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MAY 1949

STUDIES OF SUPERGLACIAL DEBRIS ON VALLEY GLACIERS

ROBERT P. SHARP

ABSTRACT. On the stagnant ice of Wolf Creek Glacier, in the Canadian Yukon, fully 90 per cent of the superglacial debris is derived from an englacial source. A mantle averaging two feet thick has developed by ablation of ice containing but a fraction of 1 per cent debris. This mantle is a heterogeneous mixture ranging from large angular blocks 15 to 20 feet in diameter to well-bedded pond deposits of clay and silt. With increasing time in the superglacial environment size and angularity of fragments are reduced, sorting is improved, and mean grain size is increased through removal of fine material by melt water. On areas of ice long stagnant, 50 to 60 per cent of the superglacial debris has been reworked by running water.

A heterogeneous and irregularly distributed superglacial mantle promotes differential ablation which is a major factor in producing and maintaining the irregular topography of stagnant ice. Layers of fine debris, even though moist, provide insulation equivalent to a foot or two of coarse debris owing to the ease with which air and water circulate through the larger openings of the latter. Ice well insulated by superglacial detritus forms irregular mounds and ridges which increase in size until progressive thinning of the debris mantle, or its removal by some independent agent, permits more rapid ablation, eventually resulting in a complete inversion of topographic relief. Under conditions now existing in the Wolf Creek area, decades are probably required for such an inversion in the areas of heavy superglacial mantle. Glacial tables, moraines, mud ridges, and other features of the superglacial mantle are also described briefly.

Dust wells and dust basins form on relatively clean ice where indirect ablation exceeds direct ablation. In this region much of the bottom silt is probably not dust. Continued deepening of wells with shaded bottoms is attributed chiefly to direct absorption of diffused radiation and partly to transmission of direct and diffused radiation through the ice. Dust basins are more largely the product of direct radiation, and their consistent east-west elongation is ascribed to greater combined retreat of the east and west walls than of the north wall alone. The division of these features into alpine- and polar-type *Kryokonitlöcher* does not hold on Wolf Creek.

The complete wasting of stagnant ice leaves an accumulation of debris reproducing on reduced scale the irregular topography of the stagnant ice and having the constitution of the superglacial mantle.

Introduction

A SIGNIFICANT part of the detritus left by many glaciers is of superglacial origin, and its nature is partly a product of that environment. Superglacial debris also influ-

ences glacial behavior, particularly in the stage of deterioration (Ogilvie, 1904, pp. 723, 725, 742; Flint, 1942, pp. 117-119), and it is a major factor in the formation of a variety of features on the ice surface. For these reasons, a more complete treatment of data previously published in abbreviated form (Sharp, 1947) seems desirable.

Field studies were made between June 26 and September 6, 1941, as part of the scientific program of the fourth Wood Yukon Expedition sponsored by the American Geographical Society. The assistance of all members of that expedition and especially of its leader, Walter A. Wood, is warmly appreciated. Research grants from the graduate schools of the University of Illinois and the University of Minnesota are acknowledged. The critical comments of Richard H. Jahns and the draftsmanship of Joan T. Rounds contributed to this study.

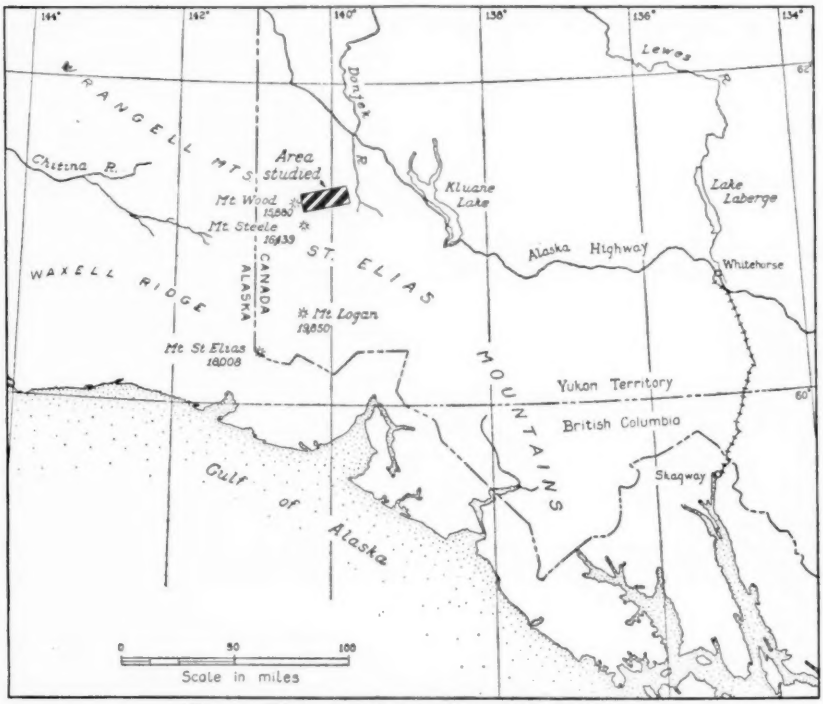

Fig. 1. Map of Wolf Creek area and environs.

PHYSICAL SETTING

The Wood expedition was conducted in the Wolf Creek region on the northeast flank of the St. Elias Range. This is in the Yukon Territory of Canada about 25 miles east of the Alaskan border at 61° 15′ N. Lat. and 140° 10′ W. Long. (fig. 1). In this region the St. Elias Range trends northwestward along the Alaska-Yukon boundary and is a rugged, glacier-bearing mountain mass with numerous lofty peaks culminating in Mt. Logan (19,850). Wolf Creek Glacier extends 25 miles eastward from 16,000-foot peaks at its head to a terminal altitude of 4000 feet. The lower 9 miles of this glacier are stagnant, but the upper part and most of the tributary ice streams are active; some receding and some advancing in 1941. This provided opportunity for observing debris on ice in different conditions of activity.

Wolf Creek is situated on the interior side of a high mountain range, so its climatic environment is distinctly continen-

TABLE I

Climatological Data for Stations on the Yukon Plateau.[1]

Station	Location with respect to Wolf Creek	Length of Record (years)	Mean Annual precipitation (inches)	Maximum Temperature recorded (°F)	Mean Annual Temperature (°F)
Burwash Landing	40 miles east	5	9.91	79	—
Whitehorse	175 miles east	9 (broken)	11.40	84	38
Carcross	200 miles east-southeast	31 (broken)	9.10	89	29
Atlin (Reed, 1941 p. 672)	250 miles southeast	18	10.94	86	—

tal, in fact almost semi-arid at the lower elevations. The climatological data in table I show a mean annual precipitation of 9 to 11 inches, a maximum temperature in the high seventies or low eighties, Fahrenheit, and a mean annual temperature between 30 and 40 degrees for the Yukon Plateau east of Wolf Creek.

[1] Data on all stations except Atlin kindly furnished by the Weather Central of the 7th Weather Group, U. S. Army Air Forces.

Much of the Wolf Creek area is probably not so dry, and the temperatures are certainly somewhat lower than at the above stations. Nevertheless, the greater height of orographic snowline here, 8800 to 9100 feet, compared to its altitude on the moister coastal side of the St. Elias Range, 2000 to 3000 feet, is indicative of the marked difference in climatic environment on opposite sides of the range. Wolf Creek Glacier suffers further from the fact that it flows eastward into areas of increasing aridity where clear skies and long hours of sunshine in summer produce extensive ablation. The climatic environment of this area must be kept in mind when making comparisons with features of ablation in other regions.

Superglacial Debris

SOURCES

Possible sources of superglacial debris are (1) material from extra-glacial areas dumped directly onto the ice below the firn line, and (2) englacial material brought to a superglacial position through lowering of the ice surface by melting. This englacial material, in turn, may be (a) extra-glacial debris dumped onto the ice above the firn line, (b) subglacial material brought to an englacial position by movement along shear planes, or (c) the ground moraine of inset and superimposed ice streams (Visser, 1932, pp. 34-39; 1935, pp. 23-24; Klebelsberg, 1938, pp. 25-39; 1939, pp. 310-311).

Most debris on Wolf Creek glaciers consists of material, formerly englacial, that has been concentrated on the surface by ablation. This is demonstrated by ice streams near the center of the trunk glacier, far from possible extra-glacial sources of debris, at least below the firn line, which have clean surfaces in their upper reaches and heavy debris mantles farther down-valley. Ten per cent or less of the detritus on Wolf Creek glaciers has been dumped onto the ice below the firn line from extra-glacial sources. By contrast, the mantle on Tasman Glacier in New Zealand (Speight, 1940, p. 134) is said to consist largely of material that has always been superglacial.

Concentrations of large angular blocks (pl. 1, fig. 1) were probably carried directly onto the glacier's surface by a rock fall or avalanche; but this may have occurred above the firn line, and the blocks could have been subsequently incorporated

within the body of the glacier. Therefore, large size and angularity do not necessarily indicate solely a superglacial history. Streams from tributary valleys have built small alluvial cones onto the surface of Wolf Creek Glacier near its terminus. These cones are exceptional, purely local concentrations of superglacial material formed only where the glacier surface has been lowered by melting so that tributary streams can flow directly onto it.

Melting of at least 500 feet of ice in the lower few miles of Wolf Creek Glacier has produced a superglacial debris mantle that would be not more than 2 feet thick if uniformly distributed. Some detritus has been carried from the glacier by meltwater and some has fallen into crevasses and other englacial openings, to be sure, but even if a one-third loss by such means is assumed, only a fraction of one per cent of the melted glacier consisted of debris. The ice exposed at present near the glacier's snout contains much more detritus (pl. 3, fig. 1), but it must be remembered that the bottom, debris-rich part of the glacier is seen here.

NATURE OF SUPERGLACIAL DEBRIS

Debris on stagnant ice is accorded major consideration here as it is abundant in this area and is the type most likely to be a recognizable constituent of glacial deposits. One must keep in mind that detritus on active ice may be considerably different. Many previous descriptions of superglacial material (Garwood and Gregory, 1898, p. 208; Ogilvie, 1904, p. 732; Tarr and Martin, 1914, p. 61; Ray, 1935, pp. 314, 315) emphasize the coarse, angular, ill-sorted nature of the rock fragments. Although this may be true for debris on active ice, it is not wholly characteristic of the material on stagnant ice in this area. The mantle on stagnant ice contains many rounded stones (pl. 1, fig. 2), considerable well-sorted debris, and some well-bedded deposits (pl. 2, fig. 2). Even so, heterogeneity is the rule, for the debris mantle on ice long stagnant consists of material that has had an extended superglacial history and shows considerable modification by superglacial processes, of material that has but recently been brought to the superglacial environment by melting and is little modified, and of material in all intermediate stages. Erratic distribution and localized accumulations of different

materials also contribute to this heterogeneity, for small deposits of well-rounded, well-sorted debris are isolated in the midst of larger accumulations of angular, unsorted fragments. Furthermore, the various ice streams composing a valley glacier not uncommonly carry debris differing lithologically from that of neighboring ice streams, and these differences are apparent in the superglacial mantle.

The debris mantle on Wolf Creek glaciers ranges from a sparse sprinkling on active ice to a nearly continuous cover 1 to 2 feet thick on stagnant ice. Somewhat greater thicknesses have developed near glacier snouts, on lateral margins, and along debris-rich bands in the ice, but such differences are overshadowed by local variations related to the topography of the ice surface (pl. 3, fig. 2). If the mantle were uniformly distributed, its average thickness would not exceed two feet, a figure notably less than the 5 to 10 feet cited by Tarr and Martin (1914, p. 206) or the 15 to 20 feet noted by Tarr (1908, p. 86) on coastal Alaskan glaciers.

The fragments in this debris range from clay and silt to huge blocks 15 to 20 feet in diameter. A casual observation gives the impression that the material is coarsest in the upper reaches of a glacier and finest near the snout. This is obviously true for the larger stones, but the progressive loss of fine material carried off by meltwater is so great that the mean diameter of the remaining debris probably increases. This conclusion is based solely on field observations and not on statistical laboratory analysis.

The size of superglacial fragments is reduced by weathering, particularly frost action, by impact of falling and rolling stones (Russell, 1893, pp. 226-227; Ray, 1935, pp. 315-316), and by the action of running water. The efficacy of weathering is demonstrated by abundant rock chips around boulders on the ice and by the shattering of some bedded and foliated rocks. Falling and rolling stones can be seen and heard in the areas of rough topography on stagnant ice (pl. 3, fig. 2), especially on warm days, and the effects of this process are shown by percussion marks and chipped areas on some boulders, and by the shattering of others. Streams of running water also are common, and the effects of abrasion during water transport are clearly evident.

Reduction in size is accompanied by a decrease in angularity,

and even though much debris on stagnant ice is noticeably angular, considerable blunting of edges and many well-rounded stones can be seen (pl. 1, fig. 2). Opposing forces are at work in this respect, for frost action and breaking by impact increase angularity, whereas the actions of most transporting agents, particularly running water, reduce it. On Wolf Creek, at least, rounding by water transportation has the upper hand.

Degree of sorting increases with time in the superglacial environment. In summer, the superglacial material is shifted by running water, by mass movement, and by free fall initiated and controlled by differential melting and stream cutting. In addition to the sorting obviously produced by superglacial water, crude sorting is accomplished in other ways. A crevasse, narrowing downward, sorts material that falls into it by letting the smaller sizes fall to deeper levels. This sorting in a vertical plane can be transferred to the surface as the glacier melts and different levels of the debris-choked crevasse are exposed. Linear accumulations of large boulders on Wolf Creek Glacier are ascribed to this process. Crude sorting at the foot of debris-mantled ice slopes, observed here and elsewhere (Russell, 1893, pp. 226-227; Ray, 1935, pp. 315-316), is attributed to the fact that large stones roll farthest and most frequently. The first is a matter of momentum, and the second of instability related to perching on ice pedestals. Small stones become firmly seated by melting into the ice. The above mechanism also accounts for the observed concentration of large stones in low places.

The work of running water in dissecting the surface of stagnant ice and in transporting and reworking large parts of the superglacial mantle is considerable. The abundance of water-worn and water-stored superglacial debris shows that running water is an agent of the superglacial environment that must not be underestimated. Not only are many streams actually observed, but long sinuous deposits of rounded stones and sorted sand or gravel mark the abandoned courses of older streams. Many of these channel deposits have now been converted to ridge cappings by differential melting. The longer debris remains in the superglacial environment, the greater the opportunity for reworking by running water, and 50 to 60 per cent of the debris on lowermost Wolf Creek Glacier shows evidence of modification by water.

The surface of many masses of stagnant ice is dotted with ice-walled ponds (pl. 3, fig. 1), in which are deposited layers of well bedded sand, silt, and clay containing occasional stones and interbeds of coarse angular gravel (pl. 2, fig. 2). The coarse debris is supplied by free fall and mass movement from the mantle on surrounding ice slopes, and finer material comes from this source and from streamlets draining into the pond. In the instance of small ice-walled ponds, there is no need to call upon ice rafting as a source of coarse debris. The impact

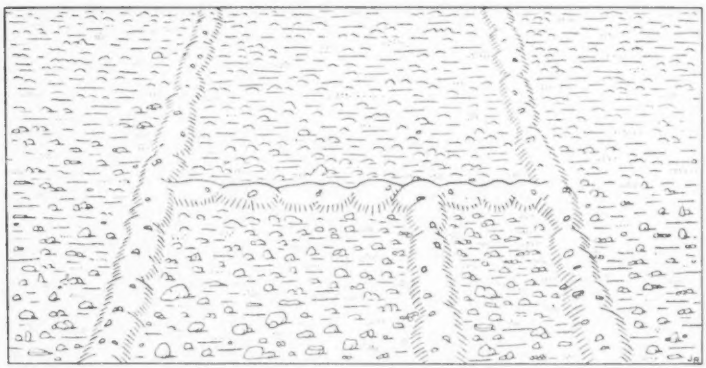

Fig. 2. Field sketch of mud ridges in superficial mantle of a Wolf Creek glacier. Ridges are 12 to 18 inches high, and area viewed is about 15 feet wide.

of large stones falling from the surrounding walls onto soft pond sediments produces small folds (pl. 2, fig. 2) with the intensity of deformation decreasing outward from the center of impact. Contemporaneity of these structures is demonstrated by truncation prior to deposition of overlying beds.

Striated stones are said to be rare in much superglacial debris (Garwood and Gregory, 1898, p. 208; Russell, 1893, p. 203; Ogilvie, 1904, p. 737; Ray, 1935, p. 317), but this is not true of detritus on Wolf Creek glaciers and on some Greenland glaciers (Salisbury, 1896, p. 806). The probable sources of such stones are: (1) Subglacial debris sheared up into the ice. (2) Ground moraine of inset and superimposed ice streams. (3) Purely englacial material scratched by shearing along planes within the ice (Garwood and Gregory, 1898, p. 223; Philipp, 1920, pp. 526-527). Most striated

Fig. 1. The largest of these blocks on the surface of upper Wolf Creek Glacier is about 15 feet across, and all are composed of the same type of granite.

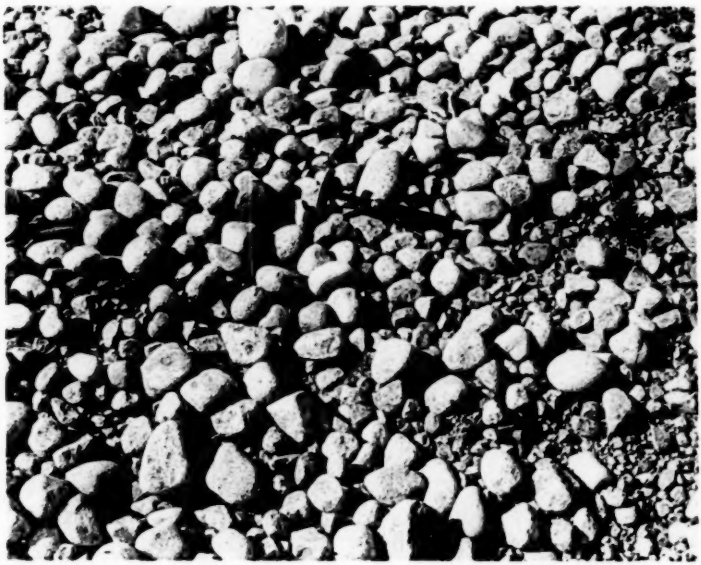

Fig. 2. Local accumulation of well-rounded stream-worn stones in Wolf Creek glacial debris.

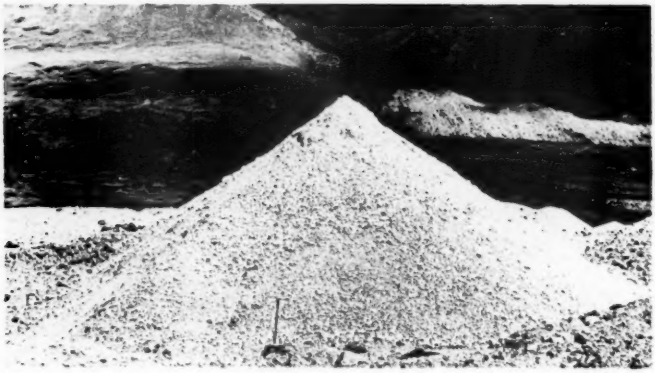

Fig. 1. Debris-covered ice cone formed because of insulation provided by a localized deposit of relatively well-sorted gravel.

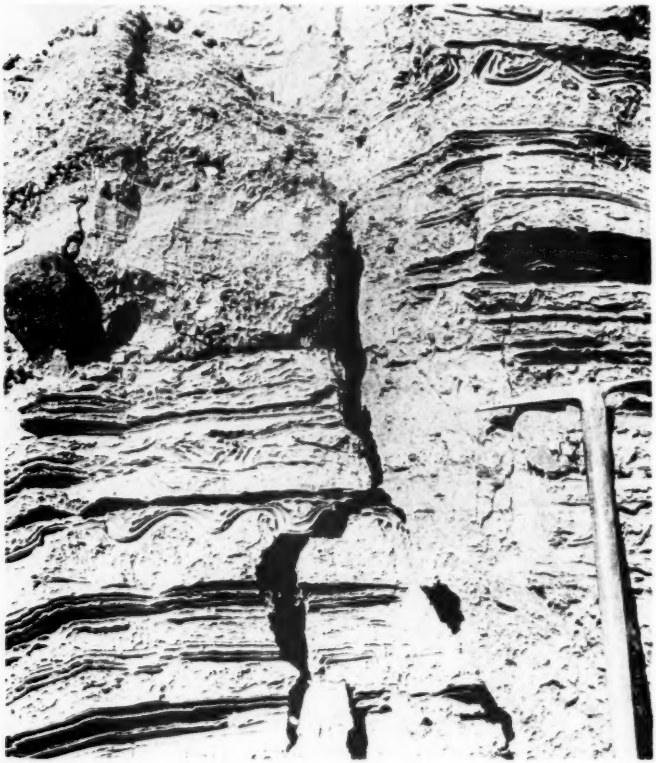

Fig. 2. Pond deposits in superglacial mantle. Folds attributed to impact of large stones fallen from ice walls of the pond which also supplied the interbeds of coarse gravel.

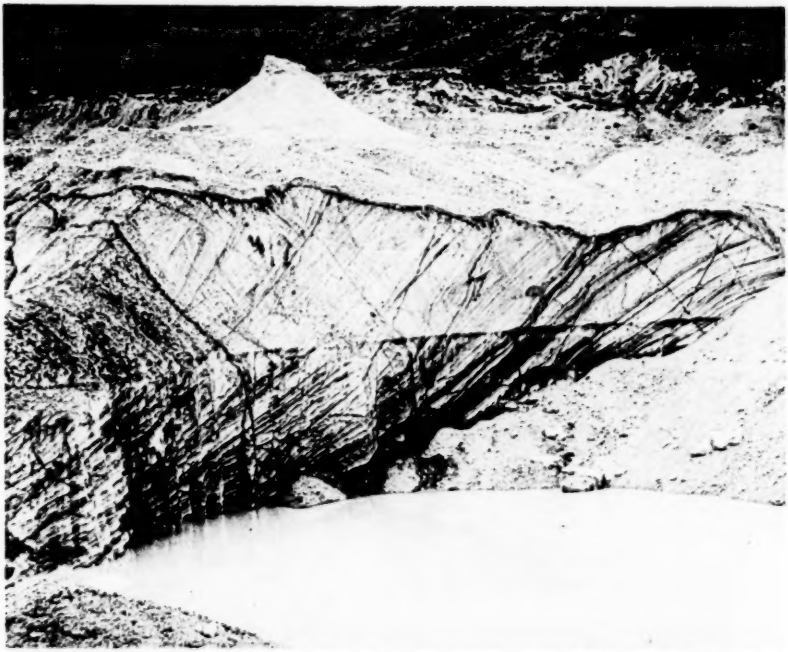

Fig. 1. Pond on surface of lower Wolf Creek Glacier. Also shown are abandoned shorelines, dipping debris bands in the ice, a debris-mantled ice mound in the background, and the thinness of the extensive superglacial mantle. Shoreline on ice face is undercut.

Fig. 2. Chaotic topography and superglacial mantle of lower Wolf Creek Glacier viewed from several hundred feet above on the north bank.

Fig. 1. Debris-covered ice cone on annual river ice of Wolf Creek area pierced by small tunnel developed by melting where mantle was removed.

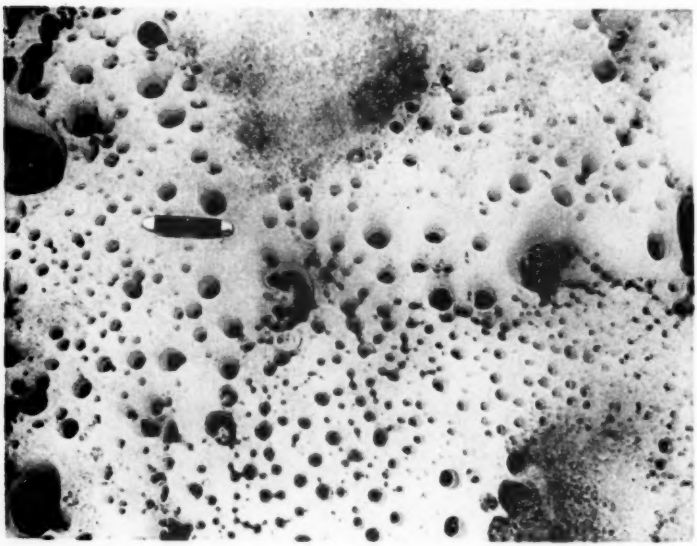

Fig. 2. Small dust wells a few inches deep perforating surface of upper Wolf Creek Glacier

stones on Wolf Creek Glacier probably come from the ground moraine of inset ice streams which are believed to be an important element in the trunk glacier (Sharp, 1947, pp. 28-30).

A few low rounded ridges of mud have been observed in the midst of coarse, ill-sorted debris on relatively level areas of stagnant ice. The ridges are 12 to 18 inches high, straight to gently curving, 5 to 20 feet long, and form intersecting sets in plan (fig. 2). The mud is rich in clay and silt and contains angular stones which are concentrated as a thin residual

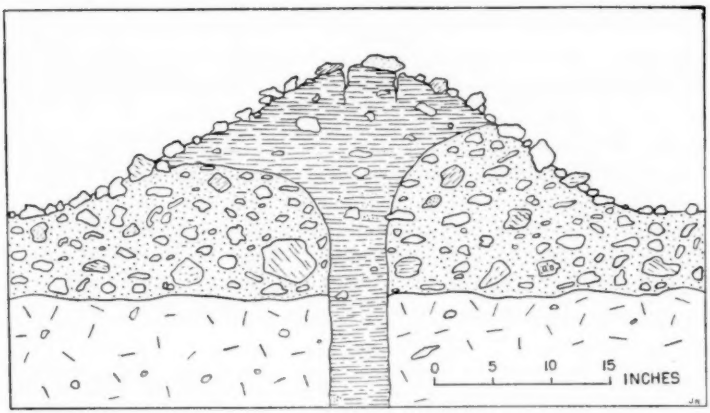

Fig. 3. Cross-section sketch of excavated mud ridge in superglacial mantle showing relation to mud-filled crack in underlying ice.

mantle on the surface. Excavations reveal steep parallel walls at depth, and lateral spreading near the surface (fig. 3). In favorable exposures the ridges are seen to mark the traces of mud-filled cracks in the underlying ice. The mud has the appearance of having been squirted out of the cracks by pressure, but squeezing seems improbable for the mud is frozen a foot or two below the surface. Instead, the ridges are attributed to down-melting of the surrounding ice leaving the mud filling of the crack standing in relief. The thawed mud spreads out somewhat on flat surfaces, and mud-filled cracks outcropping on a steep slope supply material for mudflows. The mud is finer than most englacial debris, and it may have been derived from pond deposits which once overlay this spot and filled cracks in the underlying ice.

Features on Debris-mantled Ice

Influence of debris on superglacial topography

It is a matter of common knowledge that a thin covering of debris facilitates glacier wastage because the heat-absorbing fragments melt into the ice. This process has been termed indirect ablation by Philipp (1912, p. 498). A thicker mantle insulates the ice and protects it from rapid melting, and a cover of variable thickness permits different rates of ablation and produces irregularities on the glacier surface and instability in the debris mantle. An ice mound wholly or partly stripped of its debris by running water, mass movement or some other means undergoes rapid changes in size and shape by melting of the exposed ice (pl. 4, fig. 1). Complete inversions of relief occur when an ice mound, deprived of its insulation, melts down and becomes a depression. On a rough ice surface mantled with shifting debris today's depressions may well be tomorrow's high points (Russell, 1892, p. 177; Gilbert, 1904, p. 202; Sherzer, 1907, pp. 55-57; Hobbs, 1911, p. 68; Tarr and Martin, 1914, pp. 61, 206). Comparisons of Wolf Creek Glacier photographs taken in 1935, 1939, 1941 and 1947 by Walter and Foresta Wood show many changes in topography on debris-mantled ice but no major inversions. A period of several decades is probably required for a complete inversion of the heavily mantled ice features of this area. This is longer than the several seasons estimated by Russell (1897, pp. 115-117) for coastal Alaskan glaciers, but it is in accord with Sherzer's (1907, p. 57) statement that decades or centuries are required for a complete cycle in the Selkirks of Canada. Obviously many variables enter the picture including climatic factors and thickness and nature of the debris mantle.

The thickness of debris required for the development of an ice mound or ridge depends partly upon grain size, with coarser material needing greater thickness. Layers of sand ½ to ¾ inch thick, even though moist, offer sufficient insulation for the development of mounds in areas of otherwise unmantled ice, but they do not prevent melting entirely as shown by their moist condition. Dry sand is an even better insulator (Birch *et al.*, 1942, p. 259). A one-inch cover of moist sand and silt on cones of annual river ice in this area was not sufficient to prevent their complete destruction before summer's end. How-

ever, the insulating power of such a cover is demonstrated by the rapid melting which sets in when a part is removed (pl. 4, fig. 1). Mantles of coarse debris must be a foot or two thick to provide equivalent protection. The inferiority of coarse materials must be due in part to the ease with which air and water circulate through the large openings between fragments and gain access to the underlying ice. Rain water trickling down through such openings would cause considerable melting of the underlying ice even though the debris mantle were thick. On coastal Alaskan glaciers Tarr and Martin (1914, pp. 206-207) found that 5 to 10 feet of relatively coarse debris was required to produce enough stability to permit trees to take root. With thicknesses of only 2 or 3 feet, the mantle was too active and unstable for trees to grow. These figures may not be entirely representative as in the summer of 1948 alders 3 inches in diameter were observed growing on stagnant ice of the Malaspina Glacier mantled with a cover of gravel only 13 inches thick.

DEBRIS-COVERED ICE MOUNDS AND RIDGES

Debris-mantled ridges, mounds and cones of ice are abundant on the stagnant parts of Wolf Creek glaciers (pl. 3, fig. 2) and in those areas of active ice where superglacial debris is abundant and ablation great. Similar forms are described from many parts of the world (Forbes, 1859, p. 241; Tyndall, 1874, p. 116; Russell 1892, p. 177; 1893, p. 228; 1897, pp. 13, 115-117; Gilbert, 1904, pp. 198-202; Reid 1892, p. 34; Tarr and Martin, 1914, pp. 61, 205-209; Ray, 1935, pp. 319-322; Sherzer, 1907, pp. 55-57; Hobbs, 1911, p. 168; Workman, 1913, pp. 73-75; Rickmers, 1913, p. 255; Lewis, 1940, pp. 16-26).

The Wolf Creek ridges and hillocks average 40 to 50 feet high with extremes of 10 to 150 feet. The steepest debris-covered slopes are about 30 degrees where the mantle is dry but may approach 45 degrees where the mantle is moist and fine-grained, as also noted by Lewis (1940, p. 16) and Ray (1935, p. 320). Irregularities are the product of inhomogeneities in composition and distribution of the superglacial debris and of degradational processes at work on the glacier's surface. The few truly symmetrical cones (pl. 2, fig. 1) and ridges in this area are mantled largely by water-sorted sandy gravel, and

their form reflects the homogeneity and mobility of this debris as well as the initial localization of the accumulation.

A debris-mantled feature develops and grows because the surrounding ice is lowered more rapidly by ablation. The higher a feature becomes the more thinly spread is its debris mantle, and simultaneously the mantle on the low areas becomes thicker by additions from surrounding areas and to some extent by residual accumulation from the melting ice. Obviously this produces a progressive decrease in differential ablation, and the height to which a mound or ridge can grow is determined primarily by the thickness and areal extent of the original debris accumulation. In the Wolf Creek area this limiting height is about 150 feet, but it will presumably be different in other areas owing to variations in factors controlling ablation.

LATERAL AND MEDIAL MORAINES ON ICE

It has long been recognized that lateral and medial moraines mark the outcrops of steep, debris-rich zones in glaciers (Salisbury, 1896, p. 800), and restatements of this principle (Washburn, 1935, pp. 1883-1884) hardly seem necessary. The debris composing such moraines is largely a residual accumulation of englacial detritus left on the surface by melting; only a limited amount has always been superglacial. In the ablation zone, moraines rise above the general surface as debris-mantled ice ridges, which become higher and broader with continued melting because of an increase in the amount of superglacial debris and its wider distribution by running water and mass movement.

Contortions in some medial moraines have been ascribed to deformation during passage over ice falls (Washburn, 1935, p. 1882), but on Wolf Creek the ability of a medial moraine to reestablish itself almost unchanged below an ice fall is demonstrated on several glaciers. In these instances, the surficial debris of the moraine collects in transverse crevasses formed at the ice fall. Ice ridges between crevasses are cleaned of their surficial debris by mass movements and calving, and subsequent rapid melting soon brings them to a level below the debris filling of the crevasses. Part of the debris then spills back over the unmantled ice, and surficial continuity of the moraine is reestablished. The only noticeable change is a

somewhat greater width produced by lateral spreading. Detritus lost in the deeper parts of the crevasses is replaced by the accelerated melting of shattered debris-containing ice. Medial moraines on Wolf Creek glaciers do show contortions, however, which are related to vigorous surge-like advances of tributary glaciers as suggested by Washburn (1935, p. 1882) and to adjustments within glaciers by lateral obstructed flowage controlled by both pressure and gravity.

TRANSVERSE MORAINES

Transverse moraines are debris-covered ice ridges on a glacier's surface joining a medial and a lateral or two medial moraines. They have been described (Chamberlin, 1895, pp. 204-205; Salisbury, 1896, p. 800; Chamberlin and Salisbury, 1909, pp. 296-297; Tarr, 1908, p. 87; Tarr and Martin, 1914; p. 61; Palmer, 1924, pp. 439-440; Visser, 1932, pp. 35-36; Bretz, 1935, p. 179; Klebelsberg, 1938, p. 33; 1939, p 311) under the names cross, oblique, horseshoe, melt, and pseudo-terminal moraines. Since these names are either inappropriate or have been used to designate other features, the term *transverse moraine* is suggested as most closely in keeping with the designations lateral and medial already in use. Transverse moraines are formed of debris accumulated at the end of an ice stream superimposed upon or inset within another (Workman, 1913, p. 72-73; Visser, 1932, pp. 33-39; Klebelsberg, 1938, pp. 25-31, 33). Moraines of this type have also been ascribed to crowding and pinching out of small ice streams by a more powerful glacier (Palmer, 1924, pp. 439-440; Washburn, 1936, p. 488), but the best example on Wolf Creek was at the end of an inset ice stream.

A closely similar feature is formed along the outcrop trace of parabolic debris bands in glaciers. These are probably shear zones along which debris has been carried up into the glacier from its base. François E. Matthes[2] has suggested that the debris-covered ice ridges marking the trace of such bands might be termed *transverse moraine bands.* Those seen on Wolf Creek extend entirely across a glacier from one lateral moraine to the other and are clearly concordant with the ribboned structure and thinner debris bands in the ice.

[2] Personal communication.

FORBES DIRT BANDS

Forbes dirt bands appear as a series of parallel, parabolic bands of debris on the surfaces of some valley glaciers below ice falls. They are rare, wholly surficial, and not to be confused with debris bands within the ice. Since their early description (Forbes, 1859, pp. 25, 39-41, 213-214), they have attracted attention of glaciologists and explorers (Tyndall, 1874, pp. 130-131; Sherzer, 1907, pp. 39, 50-54; Washburn, 1935, pp. 1885-1889). Fisher (1942; 1944, pp. 26-40) presents a recent study of this phenomenon. Forbes dirt bands are seemingly related to great glacier-wide crevasses developed during periodic, possibly annual, movements of valley glaciers over ice falls. Some workers hold that rapid melting of shattered ice in the crevasses during summer forms a series of broad depressions in which debris collects from the melting ice (Washburn, 1935, p. 1889) or other sources (Sherzer, 1907, pp. 50-54). Fisher (1942, pp. 8-9; 1944, pp. 30-36; 1947, pp. 139-140) concludes, however, that the crevassed areas constitute insets of relatively clean ice, so the dirt bands must be parts of the original, somewhat dirty glacier surface preserved on blocks between crevasses.

In spite of special search no Forbes dirt bands were found on Wolf Creek glaciers, although the numerous ice falls and vigorous ablation in this area would seem to favor their development. The debris of medial and lateral moraines passing over ice falls collects in transverse crevasses, as described above, and this produces local concentrations of detritus resembling segments of dirt bands. These are termed "inverted" Forbes dirt bands by Fisher (1942, p. 12), but they are short lived as they disappear when the moraines are re-established in the manner previously described.

GLACIAL TABLES

Glacial tables are isolated rock fragments perched on ice pedestals. They form because of the protection from melting afforded by the rock and are most numerous in areas covered by a sparse superglacial mantle containing large fragments. The smallest Wolf Creek tables consist of stones 6 inches to 1 foot in diameter perched on pedestals less than an inch high. The largest involve fragments several feet in diameter on pedestals as much as 4 feet high. Most have the southward tilt

reported in other parts of the northern hemisphere (Russell, 1893, p. 227; 1897, pp. 11-12; Sherzer, 1907, pp. 56-57) that is caused by greater melting on the south side, probably by reflected radiation (fig. 4). Here, the amount of tilt does not

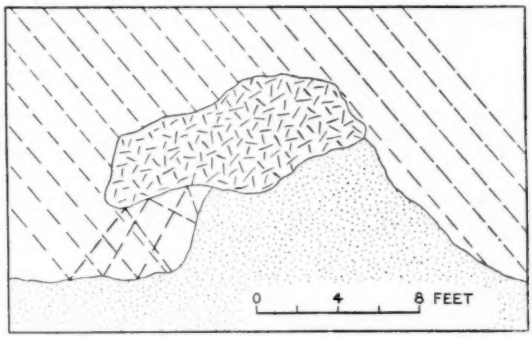

Fig. 4. Sketch showing how reflected radiation causes unequal melting and southward tilt of glacial tables in the Northern Hemisphere.

exceed 25 degrees, and the slope of the ice surface and shape of the rock fragment occasionally outweigh sun position to cause tilts in other directions. The numerous unseated tables, and the lack of pedestals higher than 4 feet are attributed to growing instability of perched boulders as the height of pedestal and degree of tilt increase. It seems that average heights of pedestals in high latitudes must be less than in low latitudes for this reason. Pedestal-type nieve penitente (Workman, 1914, pp. 320-323), formed by dislodging of perched boulders, are also present.

Size of rock fragments is an important factor in the formation of glacial tables (Hobbs, 1911, p. 167; Ray, 1935, p. 322; Tollmer, 1938, pp. 44-46), and the minimum size required increases as the season becomes warmer (Fryxell, 1933a, pp. 643-646). Color, lithology, shape, and position of the fragment are also significant. On one Wolf Creek glacier a slab of white marble 2 inches thick and 10 inches across had formed a table by mid-July while a nearby diabase of similar width but fully 10 inches thick had melted into the ice. In this case color and thermal conductivity were significant with color probably outweighing conductivity (Birch *et al.*, 1942, pp. 253, 255-256). Conductivity may have greater influence in

other instances as it differs considerably among rocks. The point, that flat slabby pieces of rock casting broad shadows form tables where smaller fragments of similar thickness do not (Hobbs, 1911, fig. 92, p. 167), was confirmed.

By mid-August glacial tables, particularly those formed by smaller stones, were seen only in the higher parts of the ablation zone. This indicates that air temperatures must be such that melting of shaded ice by conduction and condensation from the air is measurably slower than melting of unshaded ice by conduction, condensation, and radiation. The zone most favorable for development of glacial tables moves gradually up a glacier as the summer season progresses. It may also descend in fall, although the descent is probably cut short by snow fall.

Glacial tables are significant beyond the mere fact of their existence. They provide a minimum measure of ablation, but determination of the time interval involved is difficult except by direct observation. In this respect Russell's (1893, p. 227) report that tables on Malaspina Glacier seldom survive the winter is intriguing, for tables on such a glacier would afford a measure of seasonal ablation up to the time of dislodgement; and if any survived the entire summer, they would give a minimum measure of annual ablation. Russell's observation needs confirmation, however, for the means by which the stones could be dislodged in winter is not apparent. In many areas stones are dislodged from their pedestals several times a year (Fryxell, 1933b, p. 742; Tollmer, 1938, pp. 44-46), so the height of pedestal measures but a fraction of the annual ablation.

Glacial tables are further noteworthy for providing a mechanism by which superglacial stones can be shifted about independently of glacier movement, as demonstrated by Fryxell (1933b). This is brought about by the sliding and rolling of stones dislodged from ice pedestals. The direction of movement is controlled by differential melting, slope of the glacier's surface, and shape of the stone, and it may be at variance with the direction of glacier flow. The movement may also be of greater amount, than by flowage, and stones on the Teton Glacier, Wyoming, moved an average of 24.5 feet per month during summer by this process (Fryxell, 1933b, p. 742). On most Wolf Creek glaciers the direction of slope is opposed to

the direction of tilt of many perched stones so little movement results when they slip off their pedestals.

DUST WELLS AND DUST BASINS

Small holes or depressions produced by localized melting under thin accumulations of dark silt in areas of relatively clean glacier ice are known as dust wells and dust basins (Hobbs, 1911, pp. 168-169) or *Kryokonitlöcher* (Nordenskjöld, 1870). Brandt (1932, p. 86) distinguishes 6 types of Kryokonitlöcher, but only two of them, the polar and the alpine types are recognized on Wolf Creek.

Description.—Dust wells, the polar-type *Kryokonitlöcher* (Steinböck, 1936, pp. 6, 19), are small vertical cylindrical holes filled nearly to the brim with water and containing a thin layer of dark bottom silt (pl. 4, fig. 2). In places Wolf Creek Glacier is literally perforated with dust wells ¼ to 3 inches in diameter and 4 to 8 inches deep. Depths up to 24 inches have been reported from north Greenland (Philipp, 1912, p. 489), and the large-diameter wells are generally the deeper (Poser, 1933, p. 5). Small wells are circular, but large ones tend to be oval, oblong, or crudely scalloped.

An accompanying form is the larger semicircular tub or basin also filled with water and containing a layer of dark bottom silt, 1/16 to ⅛ inch thick. This is the dust basin or alpine-type *Kryokonitlöcher* supposedly predominant on temperature glaciers (Steinböck, 1936, pp. 6, 19). Elongated basins are baignoire[3] and those in which the elongation is determined by sun position are mid-day *Kryokonitlöcher* (Wagner, 1938, pp. 130-131) or *trous meridiens* (Agassiz, 1847, p. 101).

The largest dust basin observed was 3 feet long, 1½ feet wide, and 12 to 16 inches deep, but most Wolf Creek basins are about half that size and some are scarcely larger than big dust wells. Wagner (1938, p. 130) reports basins of similar size but greater depth, 30 inches, in north Greenland. Semicircular outlines predominate, and larger basins have a consistent east-west elongation, as noted by Agassiz (1847, pp. 102-103), that is independent of surface slope and structures

[3] Hobbs (1911, p. 168) spells the word "bagnoire" although the French word baignoire, meaning bath tub, is probably intended as that is the spelling used by Agassiz (1847, p. 100).

within the glacier. It parallels the banded structure of the ice only in those places where the bands are east-west.

The north wall of Wolf Creek dust basins is smoother and more gently inclined than the nearly vertical south wall (fig. 5), which is irregularly indented by remnants of small dust

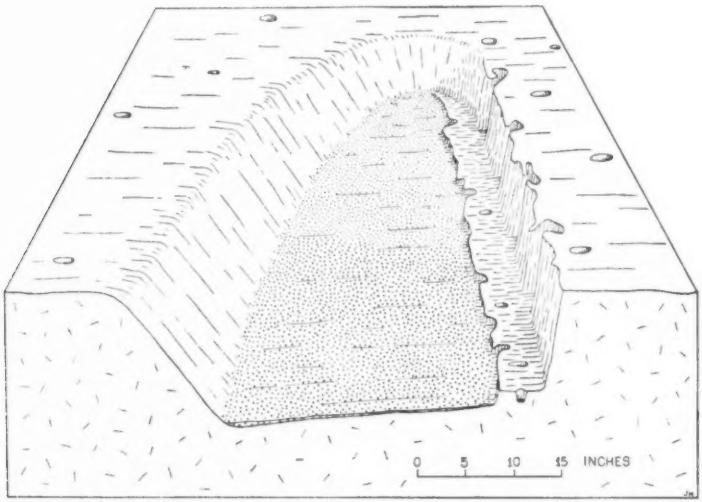

Fig. 5. Diagrammatic sketch of a dust basin showing typical asymmetrical north-south cross section, layer of dark bottom silt, sill at base of north wall, and irregularities of the nearly vertical north wall.

wells. The gentle but prevailing northward slope of the basin floor is interrupted at the foot of the south wall by a low step or sill an inch or two high. The upper surface of this sill, only partly mantled with silt, is pitted with shallow dust wells. Other parts of the basin floor relatively free of silt also project above the average level, and small pebbles on the floor may be perched on low pedestals. Basins are generally filled with water to the level of the lowest outlet.

Where dust wells and basins are abundant, their distribution and arrangement, though not shape, are concordant with the banded structure of the ice. They are most numerous in bands of white porous ice and almost entirely lacking in clear blue ice. Neither was found in ice heavily mantled with superglacial debris nor in the lower parts of the ablation zone.

Only one *Kryokonit* pool (Poser, 1933, p. 6; Wagner, 1938, p. 130; Steinböck, 1936, p. 8) was seen. This depression, 60 feet long by 30 feet wide and 12 to 15 feet deep, contained water about 4 feet deep and had a thin irregular mantle or dark bottom silt.

Origin.—Dust wells and basins are briefly noted in the English literature (Tarr, 1897, p. 141; Barton, 1897, p. 216; Sherzer, 1907, pp. 54-55; Chamberlin and Salisbury, 1909, pp. 269-271; Hobbs, 1911, pp. 167-169; Workman, 1914, p. 312; Wright and Priestly, 1922, pp. 283-286; Odell, 1925, pp. 305-306, Thwaites, 1946, p. 5), but German and Scandinavian writers provide a more detailed analysis of their origin.

Superior development of wells in northernmost latitudes and of basins in more temperate areas (Steinböck, 1936, pp. 6, 11, 15, 19) forms the basis for designating wells as the polar-type and basins as the alpine-type *Kryokonitlöcher*. However, neither type need be wholly excluded from either environment (Sherzer, 1907, pp. 54-55; Odell, 1925, p. 305; Wagner, 1938, pp. 130-131; Brandt, 1931a, p. 125), and this separation does not apply on Wolf Creek where dust wells and basins are closely associated. The fine debris in these depressions is commonly called dust, and some writers specifically speak of it as windblown (Chamberlin and Salisbury, 1909, pp. 269-271; Philipp, 1912, pp. 497, 504-505; Poser, 1933, p. 8; Steinböck, 1936, p. 19; Brandt, 1931b, p. 320). This practice is partly due to the fact that these forms were early described from the Greenland ice sheet where such fine debris is probably dust. Nordenskjöld's (Steinböck, 1936, p. 2) postulate that some of the dust is of cosmic origin has not been confirmed by chemical analyses (Poser, 1933, p. 8).

A small part of the silt in the Wolf Creek depressions may be of eolian origin, but most of it is probably fine englacial debris melted out of the ice and accumulated in small depressions on the surface by films of melt water. The material composing small mud balls on Alaskan glaciers (Ray, 1935, pp. 318-319) is presumably of this origin. In some instances the work of melt-water sheets and films in transporting the silt may be secondary and supplementary to initial distribution by wind (Workman, 1914, p. 312) or it may be primary, as thought likely on Wolf Creek, in which case the terms dust well and dust basin are hardly appropriate. *Kryokonitlöcher*

is even less appropriate since *Kryokonit* is supposedly dust of cosmic origin (Steinböck, 1936, p. 2). However, the terms dust well and dust basin have become so firmly established by long usage that they are used here regardless of the origin of the bottom silt.

The initial depressions in which silt accumulates can be formed by intergranular melting or by localized melting of exceptionally porous air-filled ice. The initial deposit is augmented by additional silt washed into the depression or by merging with neighboring accumulations.

It is agreed that these thin accumulations cause melting by absorption of direct solar radiation, but melting by this means ceases when the depth of the well is such that its bottom is continually shaded. Many wells exceed this depth, and various explanations for the over-deepening have been advanced. Drygalski (Steinböck, 1936, p. 7) favors deepening by warmed surface water which sinks to the bottom of the hole because of its greater density at 4°C. than at 0°C. Philipp (1912, pp. 490-491) suggests that deepening is produced by radiations transmitted obliquely through the ice to the silt. Wagner (1938, pp. 133-137) also favors transmitted radiations, and Poser (1933, p. 9) testifies that water and ice surrounding the silt are permeable to such radiations, which of course may be both direct and diffused. If the bottom silt is warmed by transmitted radiations, the sinking of warmed surface water to the bottom becomes less significant because the bottom water would also be warmed and correspondingly heavy.

Drygalski (Steinböck, 1936, p. 9) is said to have demonstrated that deepening of wells ceases when the surface of the water filling them freezes but is resumed when the ice layer melts. This is advanced as an argument against deepening by transmitted radiations on the basis that such deepening should continue regardless of an ice cover on the water. This argument is weakened by the possibility that the conditions causing freezing could be related to or accompanied by a decrease in radiation.

Steinböck (1936, pp. 8-9) suggests that the efficiency of transmitted rays decreases with increasing latitude owing to greater reflection from the ice surface as the sun's elevation becomes lower. He also holds that diffused radiations from the sky reach the bottom of wells directly, but Wagner (1938, p.

132) questions the efficacy of this process and maintains that only 1 per cent of the total radiated energy can reach the bottom of the average well as diffused radiation. This would scarcely be enough to produce melting at a rate greater than the lowering of the ice surface by direct ablation. However, Wagner may have underestimated the amount of diffused radiation which reaches the bottom of a well, for on clear summer days diffused heat rays constitute as much as 1/8 to 1/3 of the total solar radiation (Lundegårdh, 1931, p. 4), and the amount of diffused radiation increases directly as the cloud cover to approximately 100 per cent of the total radiant energy. Wright and Priestly (1922, p. 5) also note that at very low solar altitudes the "sky radiation" on a horizontal plane is more intense than direct solar radiation. Thus, at high latitudes and in cloudy weather diffused radiation may play a much larger role than imagined by Wagner, and certainly some of the energy transmitted through the ice arises from diffused radiation.

The possible effect of radiations reflected to the bottom of the hole from its walls is difficult to evaluate but is thought to be an additional minor factor. Steinböck (1936, pp. 10-11) reports that organisms living in the bottom mud (Sherzer, 1907, pp. 45-55) generate some heat, and this may be a further means of deepening the wells.

Final conclusions on the relative significance of these various factors do not yet appear possible, but it would seem that if one imagines himself at the bottom of a dust well he would see more light, and therefore more energy, coming in as diffused radiation at the top of the well than as transmitted radiation through the walls. For this reason it is suggested that of all the above mentioned factors diffused radiation is probably the most effective in deepening the dust wells after the bottom is shaded from direct radiation.

Dust basins are of the same genus as dust wells, but the relative efficacy of genetic agents is different. Some basins may be formed by melting under initial accumulations of silt or through the gathering of such debris into pre-existing shallow depressions (Poser, 1933, p. 17). Others are developed by integration of adjacent dust wells (Hobbs, 1911, p. 167; Philipp, 1912, p. 497; Brandt, 1932, p. 93). Direct radiation has a relatively large part in forming basins by virtue of ready

access to the floors and walls. In northern latitudes lateral enlargement takes place chiefly through melting of the north, east, and west walls by direct radiation. The north wall becomes especially smooth and acquires a slope about normal to the sun's rays (Wagner, 1938, p. 136). In northern latitudes the south wall and the basin floor at its foot are in shadow. This accounts for the irregularities of the south wall and adjacent basin floor, for melting there must be by transmitted, diffused, and reflected radiations or by convection and conduction in the air and water. Most irregular indentations of the south wall and small depressions on the basin floor are remnants of incompletely digested dust wells overtaken by the retreating walls, although some may be a later development.

Northward slope of the basin floor results from greater exposure to direct radiation on the northern part of the floor. Pebbles perched on small pedestals on the floors of some dust basins give further proof that much of the bottom melting is by direct radiation. The lip of the sill at the base of the south wall marks the edge of the mid-day shadow, and the height of this sill, an inch or two, measures the superiority of melting by direct radiation over melting by all other means.

The consistent east-west elongation of dust basins on Wolf Creek, in the Alps (Agassiz, 1847, pp. 102-103), and in the Himalayas (Workman, 1914, p. 312) is related only locally to visible structures in the ice. The elongation on Wolf Creek is ascribed to the greater amount of radiated energy received by the east and west walls together than received by the north wall alone, despite the recognized efficacy of the mid-day sun. Combined retreat of the east and west walls is therefore greater and an east-west elongation results.

According to Wagner (1938, pp. 134, 137) dust basins are developed largely in porous air-filled ice because it is a poor conductor of radiations, and they are converted to heat. Contrariwise, dust wells are supposedly formed in clear ice because it is a better conductor, and the radiations are transmitted to the bottom silt. This thesis is not confirmed on Wolf Creek as both depressions favor porous ice, and Ahlmann's (1935, p. 104; 1938, p. 417) observation that ice absorbs more radiation than snow suggests that Wagner's conclusions may not be universally applicable. An alternate possibility is that melt water washes fine debris off the smooth surface of clear ice

before it has time to become firmly seated by melting. This might not occur if the temperature were always below freezing and no melt water were available, and the nature of the ice in which dust holes form need not be the same everywhere.

The localized melting that produces wells and basins is called indirect ablation (Philipp, 1912, p. 498) or *Kryokonitablation* (Poser, 1933, p. 10). Observations and experiments (Brandt, 1931a, p. 126; 1932, pp. 88-91) show that clear cold weather with much radiation favors development of wells and basins by allowing indirect ablation to proceed at a faster rate than direct ablation. Warm cloudy weather produces more surface melting by convection, conduction, and condensation and is less favorable to the development of dust holes. If direct ablation becomes superior, it can eventually destroy the dust holes. The maximum depth attained by these features is controlled by the relative rates of direct and indirect ablation (Brandt, 1931a, p. 126), and in some areas wells and basins are deeper in spring and early summer than later in the season when direct ablation becomes greater (Poser, 1933, p. 10). In late summer, dust holes on Wolf Creek glaciers were limited to a narrow zone lying just below the firn line. Their absence from lower parts of the ablation zone is attributed to the superiority of direct ablation there. With advance of the summer season, the zone of dust wells and basins probably moves slowly up the glaciers, following the retreating snowline.

Dust wells and basins are instrumental in causing melting at air temperatures far below freezing (Philipp, 1912, pp. 489-490; Workman, 1914, pp. 313-314). They may be a major factor in glacier ablation in high latitudes and at high altitudes (Hobbs, 1944, p. 82).

Steinböck (1936, pp. 9-11, 20) suggests that the relative effectiveness of direct radiation in middle latitudes and of diffused radiation farther north accounts for the development of polar- and alpine-types of *Kryokonitlöcher*. Wagner (1938, p. 137) believes it is more a matter of ice condition, with clear ice in the north favoring development of wells and air-filled ice in the south favoring basins. Insofar as basins are formed through integration of wells, they are both the result of the same processes, although direct radiations are of more significance in developing basins and diffused and transmitted radiations of greater effect in forming wells. Integra-

tion of wells to form basins probably occurs less easily in areas where the air temperature is continuously below freezing than in warmer regions because back-melting of the walls by conduction is less. Thus, air temperature may be as fundamental as any other factor in accounting for the abundance of wells and scarcity of basins in far northern latitudes. It is possible that wells in regions like Wolf Creek are formed chiefly in the spring and fall, and basins develop largely in mid-summer when air temperature rises above freezing for longer periods.

In summary, dust wells and dust basins are found on relatively clean parts of Wolf Creek glaciers where indirect ablation exceeds direct ablation. In this area much of the bottom silt need not be dust. Over-deepening of dust wells seems to be due largely to diffused and transmitted radiations, and dust basins are more largely the product of direct solar radiation. East-west elongation of the basins is independent of ice structures and is ascribed to the greater combined melting of the east and west walls than of the north wall alone. The separation of alpine- and polar-type *Kryokonitlöcher* does not hold on Wolf Creek.

Relation to Glacial Deposits

The transition from superglacial accumulation to glacial deposition is accomplished in the final stage of glacier degradation where the ice thins, stagnates, and ultimately disappears. All superglacial materials and features described above are subject to alteration as long as they are underlain by ice, and many, such as glacial tables, dust wells and dust basins, will be destroyed. The amount of modification to be expected during this transition decreases as the ratio of debris to ice increases. In the final stage the debris mantle may be so thick and melting so slow that the melt water filters off gradually without reworking the detritus. However, the space vacated by melting ice must be filled, so some modification of superglacial forms is inevitable. Large depressions extending through the glacier to its floor are rare, and Cook's (1946, pp. 575-577) perforation mechanism appears to be based on improbable assumptions (Holmes, 1947, p. 244). In the Wolf Creek area glacier ponds enlarge themselves by lateral undercutting and melting of the ice walls (pl. 3, fig. 1), but there is every

indication that rapid accumulation of bottom debris prevents deepening by melting except possibly in the initial stage.

Complete wastage of stagnant ice heavily mantled with superglacial debris leaves an accumulation having the constitution and topographic form of the superglacial mantle. However, the topographic relief will be on a smaller scale, for it can be no greater than the thickness of the superglacial mantle. In constitution the material may range from well-sorted and well-bedded clay, silt, sand, and gravel to an ill-sorted mixture of large angular blocks. In general, it will be distinguished by its loose texture, lack of clay and silt, except in pond deposits, and evidences of reworking by running water.

In the instance of valley glaciers, streams of melt water coursing over the valley floor usually rework and largely destroy such accumulations, although they may be preserved in protected spots. Areas of continental glaciation afford better opportunity for preserving accumulations of superglacial origin.

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California Institute of Technology
Pasadena, California

THERMODYNAMIC RELATIONS OF IMMISCIBILITY AND CRYSTALLIZATION OF MOLTEN SILICATES

TOM. F. W. BARTH AND TERKEL ROSENQVIST

ABSTRACT. The relations of immiscibility and of crystallization in silicate melts and magmas are discussed. On the basis of the ionic constitution of the melts it can be said that regions of immiscibility may exist at composition, temperature, and pressure ranges which have not been explored in the laboratory.

During fractional crystallization of a silicate system the regular progressive precipitation of the cations and of the anions is governed by the relations of the E-values (activation energies of migration), and of the pO-values (oxygen ion concentrations) respectively.

INTRODUCTION

MODERN igneous geology has developed in consequence of a rapidly increasing knowledge of the crystallization processes of silicate melts. But thus far little has been known about the physicochemical properties of the melts, and practically nothing has been applied to geological problems. In recent years pertinent experimental data have accrued from many sources, and it now would seem possible to discuss some of the results of direct bearing on petrology.

In the constitution of silicate melts lies the key to the problem of the interesting appearance of liquid immiscibility and to the nature of the solid phases which may crystallize out. Liquid immiscibility was first discovered in silicates by Greig (1927) and has aroused much discussion, but the consensus of opinion has been that no geological significance could be attached to it. However, the discussion now has been revived by Fenner (1948), whose paper on immiscibility of igneous magmas was published while the present manuscript was in preparation. Fenner maintains that immiscibility is thermodynamically probable, discusses the petrological implications, and presents field evidence for its occurrence in natural magma.

In the present paper certain properties of artificial melts only will be discussed, and no attempt will be made to survey the applications to geology.

CONSTITUTION OF SILICATE MELTS

The entropy of fusion of silicates is not high, so that no major changes in structure are to be expected on melting.

On general grounds one would, therefore, expect the liquid structure to resemble the solid. Experiments have confirmed this: see e.g. Blitz (1934), Biscoe et al. (1938), Endell (1942), Martin (1943), Zachariasen (1932).

Molten silicates possess an *ionic* constitution in analogy with solid silicates. The extent of ionic dissociation is comparable to that of aqueous solutions of strong electrolytes.

Typical cations are Na^+, K^+, Ca^{2+}, Mg^{2+}, Fe^{2+} which occupy no fixed positions in the melt but exhibit a high degree of mobility.

The anions are predominantly polymerized silicon-oxygen tetrahedra linked together by oxygen bridges to one-, two- or three-dimensional networks. The network is similar to that found in crystalline silicates but more irregular.

The bonds between the central silicon ion and the oxygens at the corners of the tetrahedra are mainly covalent, but may also be regarded as a largely polarized ionic link (which means the same).

A verification of the existence of a polymerized silica-network is given by the high viscosity of silicate melts. The viscosity is found also to increase upon adding Al_2O_3. This shows that Al can replace Si in the polymerized anion, as it does in some crystalline silicates, e.g., feldspars. To a certain extent three-valent iron forms anions, probably of the form $(FeO_6)^{9-}$.

In addition to the anions mentioned above, the melt contains small amounts of free oxygen ions, 0^{2-}, the amount of which is determined by the following reactions:

$$\begin{aligned}
(SiO_4)^{4-} &\rightleftharpoons (SiO_{3.5})^{3-} + \tfrac{1}{2}\, O^{2-} \\
(SiO_{3.5})^{3-} &\rightleftharpoons (SiO_3)^{2-} + \tfrac{1}{2}\, O^{2-} \\
(SiO_3)^{2-} &\rightleftharpoons (SiO_{2.5})^{1-} + \tfrac{1}{2}\, O^{2-} \\
(SiO_{2.5})^{1-} &\rightleftharpoons (SiO_2) + \tfrac{1}{2}\, O^{2-}
\end{aligned}$$

For each reaction we can write the corresponding equilibrium equation, for example:

$$\frac{[SiO_{2.5}] \cdot [O^-]^{1/2}}{[SiO_3]} = K \quad \ldots\ldots\ldots\ldots\ldots\ldots (1)$$

where the square brackets indicate the activity of the components, and K is the equilibrium constant.

The activity of the oxygen ion may be taken proportional to its concentration, and it is readily seen that a large oxygen ion concentration pushes the reactions to the left, i.e., the oxygen ion concentration increases with increasing basicity of the melt. It becomes appreciable in melts of more basic com-

position than that corresponding to an orthosilicate. Thus the so-called "pO-value" is a measure of the basicity of the silicate melt.

In formal analogy with the symbol pH, the oxygen ion activity is indicated by its negative logarithm and denoted by the symbol pO.

The degree of polymerization is markedly influenced by the nature of the cations present. This means that the nature of the cation influences the activity coefficient of the different types of macroions. The effect is that at constant basicity the formation of oxygen bridges is favored by a weakly polarizing ion, as K^+, and decreases in the sequence K^+-Na^+-Li^+. Flood and Förland (1947) have shown that at a certain basicity where the K silicates contain anions with about *2.5* oxygen/Si, the Na silicates have *3* oxygen/Si, and the Li silicates *4* oxygen/Si. This is in agreement with the fact that in the alkali silicate melts the viscosity decreases in the sequence $K > Na > Li$, i.e., with increasing polarizing power of the cation. See e.g. the compilations by Eitel (1941).

It is probable that in silicate melts containing earth-alkali and ferrous ions, the tendency is even greater towards a breaking up of the macroions into smaller units. This is indicated also by the fact that the viscosity of iron silicate melts is rather low even up to high SiO_2 content.

When CO_2 is dissolved in molten silicates it reacts with the oxygen ions to form CO_3^{2-} ions.

$$CO_2 + O^{2-} \rightarrow CO_3^{2-}$$

At constant CO_2 pressure the amount of CO_2 dissolved (the concentration of CO_3^{2-}) will be approximately proportional to the oxygen ion activity of the melt. This is the method used by Flood to determine oxygen ion activities.

When H_2O is dissolved in the melt the following reaction takes place

$$H_2O + O^{2-} \rightleftharpoons 2(OH)^-,$$

in harmony with the fact that $(OH)^-$ is an individual building brick in the crystal structure of many silicate minerals.

LIQUID IMMISCIBILITY

Silica melts and melts of Na_2O, K_2O or Al_2O_3 are known to be completely miscible in the low-temperature region. But silica shows only partial miscibility with melts of CaO, MgO, ZnO, FeO, Fe_2O_3: at high contents of SiO_2 an area of immis-

cibility exists. The effect of the various oxides is of considerable interest. The elements of the vertical column of the periodic table Mg, Ca, Sr, Ba, exercise, with increasing basicity, a successively decreasing effect; next follow the alkali metals Li, Na, K, Rb, Cs. The shape of the various melting curves is interesting: not until Rb and Cs is the normal shape restored. See Kracek (1930).

Strongly polarizing cations produce two effects: They raise the activity coefficient of highly polymerized silicon-oxygen networks, and favor the formation of individual (SiO_4)-groups. Under certain conditions melts high in (SiO_4)-groups will, therefore, unmix from melts of highly polymerized silicon-oxygen networks. These two melts will be referred to as ortho-melts and para-melts, respectively.

In various ternary systems of rock-making oxides a region of immiscibility appears. Again highly polymerized para-melts separate from melts rich in (SiO_4)-anions. But no complete investigation of any binary or ternary silicate system has been attempted at temperatures somewhat above those of crystallization, nor is the effect of pressure on the solubility gap known.

Our ignorance is deplorable, for a complete knowledge of the solubility relations would be of the greatest value for the theory of magmatic differentiation. Since the experimental data are incomplete, it is impossible at present to predict anything regarding the general immiscibility relations in silicate systems. However, it can be said that regions of immiscibility may exist at composition, temperature, and pressure ranges which have not been explored. It is not permissible, therefore, on the basis of present knowledge, to conclude that differentiation by magmatic immiscibility is impossible or unlikely. For all we know, it may be widespread.

The preceding conclusions are supported in a general way by Büchner (1906) and by Findlay (1935) [See also Marsh (1935) and Hildebrand (1936)].

According to the general discussion presented by Findlay the solubility curve of two partially miscible solutions may show either an upper or a lower critical solution temperature, above or below which complete miscibility exists. Investigations of a number of systems containing organic liquids indicate that the general form of the concentration-temperature curve is that of a closed ring. Theoretically this ring may be

cut off by the stability fields of crystalline phases, as actually observed in dry silicate melts where the lower portion of the hypothetical ring is dissected. Experiments show that by pressure the lower critical solution temperature is always raised, the upper may be either raised or lowered.[2] According to a recent review in Chem. and Eng. News, Sept. 1948 (p. 2877) a lower critical solution point has been found by Secoy in the system UO_2SO_4-H_2O under pressure.

The idea presenting itself on the basis of the facts just mentioned is that certain silicate systems may possess regions of immiscibility at higher temperatures although no immiscibility has been encountered close to the temperatures of crystallization. It is furthermore conceivable that under pressure the solubility gap in, say, the system CaO-SiO_2 would disappear *at the temperature of crystallization*, but exist in the shape of a closed ring at elevated temperatures. An analogy to this may exist in the system BaO-SiO_2 at ordinary pressure: the shape of the crystallization curve here indicates that an area of immiscibility exist in the neighborhood, perhaps as indicated in figure 1.

In a system of two partially miscible liquids the addition of a foreign substance will expand the region of immiscibility if the solubility of the foreign substance is markedly different in the two liquids. In view of this fact the effect of carbon dioxide and water (and fluorine) may be considered.

Water and carbon dioxide are more readily dissolved in ortho-melts than in para-melts; therefore, the immiscibility relations will be affected and the solubility gaps may be widened by the addition.

It has been shown by Tuttle and Friedman (1948) that the system Na_2O-SiO_2, which is miscible in all proportions, splits by addition of H_2O, into two immiscible liquids, one very rich in water (corresponding to an ortho-melt?), one rather rich in silicate (corresponding to a para-melt). The immiscibility region has the shape of a spheroid. The upper extent is not known, but parts of the upper portion are cut by the stability fields of $Na_2Si_2O_5$ and quartz. The lower portion is not cut off

[2] Theoretical considerations suggest that the immiscibility of a conjugate pair of liquids of simple molecules or atoms (e.g., alloys) continues to increase with decreasing temperature. But if one or more of the constituents of the liquids undergo polymerization or inter-molecular rearrangement by cooling, then a lower critical point is possible. This situation is often encountered in mixtures of organic compounds, of sulfur, etc. Likewise, it is to be expected in silicates.

by any stability fields of crystalline phases, but shows a lower critical solution temperature between 200 and 250°C, below which complete miscibility occurs.

It is of more than usual interest that the immiscibility spheroid in this system possesses a lower consolute point. It demonstrates that, in this silicate system, the theoretical behavior illustrated by figure 1 has been realized.

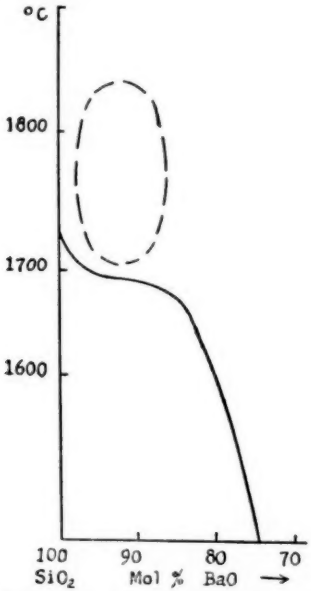

Fig. 1. The liquidus curve in part of the system SiO_2-BaO. A hypothetical region of immiscibility is indicated.

This fact lends added support to the view expressed above that immiscibility in silicate melts would take place in closed regions possessing a definite downward termination, and that such regions may be present in certain silicate systems at temperatures well above crystallization.

CRYSTALLIZATION IN SILICATE MELTS

The theory of crystallization and melting may be studied from many angles. The distinction between melt and crystal may be said to consist, e.g., in the degree of order of the ions. At the point of crystallization an ordered arrangement becomes themodynamically stable, or, put into other words, for

a given composition the activity of the constituent ions becomes lower in an ordered state than in the melt.

During fractional crystallization more and more ions gradually pass from the molten into the solid state. Wickman (1943) has shown that the so-called E-values (the activation energies of migration) of the various ions constitute a decisive factor in determining the sequence of crystallization of the several cations. Thus is explained why, in ordinary rock magmas, the ratios Fe:Mg, and alkali:lime increase with increasing crystal-fractionation.

The fractional crystallization of the anions may be understood from a study of their activity relations: Under the prevailing pO-conditions during the cooling of an ordinary basaltic magma two types of anions preserve a high activity in the melt, and therefore, appear in the first crystallization products, viz., (1) the orthosilicate anion, (SiO_4), and (2) the highly polymerized anion $[Si_{\frac{1}{2}}Al_{\frac{1}{2}}O_2]_n$. It is of more than ordinary interest that these two crystallization products in their ionic constitution are respectively analogous to the two immiscible liquids (ortho-melt and para-melt) as discussed above. It shows that homogeneous magma has an intrinsic tendency to break up into two parts that are either liquid or solid, the one rich in orthosilicate anions, the other rich in parasilicate anions, corresponding respectively to the beginning of the ferromagnesian (olivine) reaction series, and the feldspar (anorthite) reaction series of Bowen.

The reason for the well-known evolution of the ferromagnesian reaction series, olivine → pyroxene → hornblende → mica is given by equation (1). Early crystallization of olivine rids the magma of both (SiO_4)-anions and Mg-Fe cations; thus, the basicity decreases and anions of successively lower oxygen-silicon ratios increase their activity. Consequently, chain and sheet silicates [corresponding to pyroxene (hornblende) → mica] follow the crystallization of olivine.

The study of the crystallization of the aluminum-silicon-oxygen anions is not so far advanced. The high activity of the polymerized anorthite anion at low pO-values is not yet confirmed by experimental data. However, the reason for the development of the reaction series anorthite → albite is obviously related to the great thermal stability of three dimensional frameworks in which the ratio Si:Al is 1:1, as already pointed out by Wickman, loc. cit. With increasing fraction-

ation (and increasing pO-values) the ratio Si:Al increases to 3; consequently, a series of successively more acid (albitic) plagioclases follow the crystallization of anorthite.

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Department of Geology and
Institute for the Study of Metals
University of Chicago

A NEW SPECIES OF *PALEORHINUS* FROM THE TRIASSIC OF TEXAS[1]

WANN LANGSTON, JR.

ABSTRACT. A new species of paleorhinid phytosaurs, *Paleorhinus scurriensis*, from the basal Dockum of Scurry County, Texas, is described. The lateral position of the quadrate foramen first reported in *P. bransoni*, is corroborated and is considered characteristic of the genus. The otic opening is present as a deep notch rather than as a completely bounded foramen as described in *P. bransoni*, and there is therefore more reason to suspect misinterpretation of this region in the genotype. A further instance of the presence of a probable persistent parietal foramen in an immature phytosaur is noted. Youthful characters in the genus are discussed and the species is compared with other phytosaurs. Observations are offered on the geologic significance and provisional limitations are placed upon Dockum-Popo Agie correlation.

INTRODUCTION

RECENT examination of the Triassic vertebrate material housed in the West Texas Museum (Texas Technological College) has revealed the presence in that collection of a number of hitherto unrecognized forms from the Dockum group of Western Texas. Among these is a skull of a small phytosaur collected in 1937 by Dr. John Clark on the farm of Mr. H. G. Bryan some two and one half miles northeast of Camp Springs, Scurry County, Texas. The horizon may be referred to the basal Dockum[2] which in this area is a fine to coarse sandstone and conglomerate which, although white in an unweathered state, appears brownish after prolonged exposure.

The skull when found was enclosed in a concretionary mass of white, fine-grained, calcareous sandstone that has served to protect the bone from rapid disintegration. The greater portion of the snout, the upper and lateral surfaces in the orbital region, and the lateral bones surrounding the temporal fenestrae are lacking. Otherwise the skull is free of distortion and the majority of the sutures are remarkably distinct. Unfortunately the palatal and posterior cranial regions have not been completely freed from the matrix and therefore these areas are only partly available for discussion.

[1] Expenses connected with the preparation of the present paper were defrayed by the Research Council of the Texas Technological College, Lubbock, Texas.

[2] Beede and Christner (1926) have proposed the name Camp Springs conglomerate for the basal Dockum of this region, but due to the discontinuity inherent in the Dockum sediments it seems best at present to consider the Camp Springs conglomerate as of only local importance.

The skull is of the general phytosaurian form, small in size, longirostrine, and somewhat depressed dorso-ventrally. The extreme anterior position of the external nares suggests a close relationship to the genus *Paleorhinus* Williston. The presence of a lateral quadrate foramen, confirmed by the present specimen, appears now to be characteristic of the genus and offers further evidence of the generic identity of the two specimens. The general proportions of the skull and the unusual construction of the narial structures is similar to that found in *Paleorhinus parvus* Mehl, and it is therefore assumed that the present specimen is more closely allied to that species than to *P. bransoni.* The relative smallness of the present skull (estimated length 550 mm.), the decidedly uncrowded arrangement of the maxillary teeth, and the apparent presence of a persistent parietal foramen attest the immaturity of the individual.

Unfortunately the type specimens of *Paleorhinus* leave much to be desired from the standpoint of preservation. In many respects the present specimen is in better condition than the other two, but because of this fact comparison with them is rendered extremely difficult. Were all three typical *Paleorhinus* skulls equally well preserved many seeming differences in cranial construction might disappear. The writer, however, is of the opinion that such characters as the dorso-ventral flattening of the skull, the exceptionally large palatine foramina, and the moderately elongate posttemporal fenestrae, are of sufficient importance to separate the present form from the previously described species.

ORDER Thecodontia
SUBORDER Phytosauria
FAMILY Phytosauridae
SUBFAMILY Phytosaurininae Camp

Paleorhinus scurriensis n. sp.

HOLOTYPE: Incomplete skull, W. T. Mus. Pal. Col., No. 539.

HORIZON: Basal Dockum, Triassic (Camp Springs conglomerate).

LOCALITY: Two and one-half miles NE of Camp Springs, Scurry County, Texas.

DIAGNOSIS

Small paleorhinid phytosaur; nares anterior, quadrate

foramen posterior in position, but visible in lateral aspect. Skull flattened dorso-ventrally. Internarial septum composed of premaxillaries and nasals; septomaxillaries not meeting in the median line. Palatine foramina very large; posttemporal fenestrae elongate. Persistent parietal foramen probably present in immature individuals.

OPENINGS IN THE SKULL

The pronounced anterior position of the narrow and elongate external nares in *Paleorhinus scurriensis* is even more striking than in the previously described species of *Paleorhinus*. They look upward and slightly forward, the posterior borders being somewhat more elevated than the anterior rims. They are transversely wide behind, but become progressively narrow in the anterior direction and finally disappear in narrow slots on the upper surfaces of the septomaxillaries.

The choanae are elongate, narrow openings situated in the palatal vault on either side of a thin but vertically broad median septum. They are situated some distance behind the posterior limits of the external narial openings.

The relatively small antorbital fenestrae are oval in outline. The left opening is slightly larger than the right, the former measuring some 64 mm. by 32 mm. along the extreme axes. They extend forward to a point some 36 mm. behind the posterior limits of the external nares. The openings are only partially visible in lateral aspect although they may be seen in their entirety from above. The lateral areas of the skull immediately surrounding the antero-superior and posterior margins of the fenestrae are sharply depressed in a manner similar to that seen in *P. bransoni*.

The median and posterior rims of the superior temporal fenestrae are preserved on both sides of the skull and indicate that these openings were broadly oval in outline.

The boundaries of the lateral temporal fenestrae are completely lacking, but the extreme thinness of certain portions of the right jugal and squamosal indicate that these areas were not far removed from the borders of the openings on that side of the skull.

A small portion of the frontal rim of the right orbit is preserved. Apparently the orbits were directed upward and

outward. The transverse diameter of the frontals between them seems to have been somewhat less than in *P. bransoni.*

Unfortunately the various foramina situated in the cranial region have not been freed from the matrix. Numerous fossae can be seen leading into the general vicinity of them, but their actual positions cannot be determined.

The quadrate foramina, represented by a small portion of the right opening, were visible in lateral aspect although their position was somewhat more posterior than in *P. bransoni.*

The foramen magnum is nearly round in outline.

The posttemporal fenestrae are elongate and vertically narrow. They are larger than in the skull of *P. bransoni,* but are, nevertheless, relatively smaller than in the majority of the larger phytosaur species.

The palatine foramina in *P. scurriensis* are large, elongate openings bounded medially by the palatines and laterally by the ectopterygoids and maxillaries. The total area of each opening appears greater than in any other genus with the possible exception of *Angistorhinus.*

INDIVIDUAL SKULL ELEMENTS

PREMAXILLARIES: Only the posterior portion of the premaxillaries is available for discussion. When seen from above the bones are relatively smooth, strongly rounded transversely on the upper surface, and meet each other in the median line. They are not separated posteriorly by interjection of the septomaxillaries, but, as described in the following paragraphs, continue into the narial opening forming the greater part of the internarial septum. Elsewhere the premaxillaries are excluded from the narial rim by the septomaxillaries and the nasals. They terminate laterally some 40 mm. anterior to the antorbital fenestrae, in a sharp tapering process which separates the nasals and the maxillaries in this region of the skull. Ventrally the premaxillaries are strongly vaulted forming the roof of the anterior portion of the palate. On either side of the median line there is a strong, sharp ridge running longitudinally on the inside of the alveolar trough. Similar alveolar ridges, although reported in the majority of the phytosaurs including *Paleorhinus bransoni,* are, however, described as being "little developed" in *P. parvus* (Mehl, 1928). This ridge dies out posteriorly on the palatal surface of the

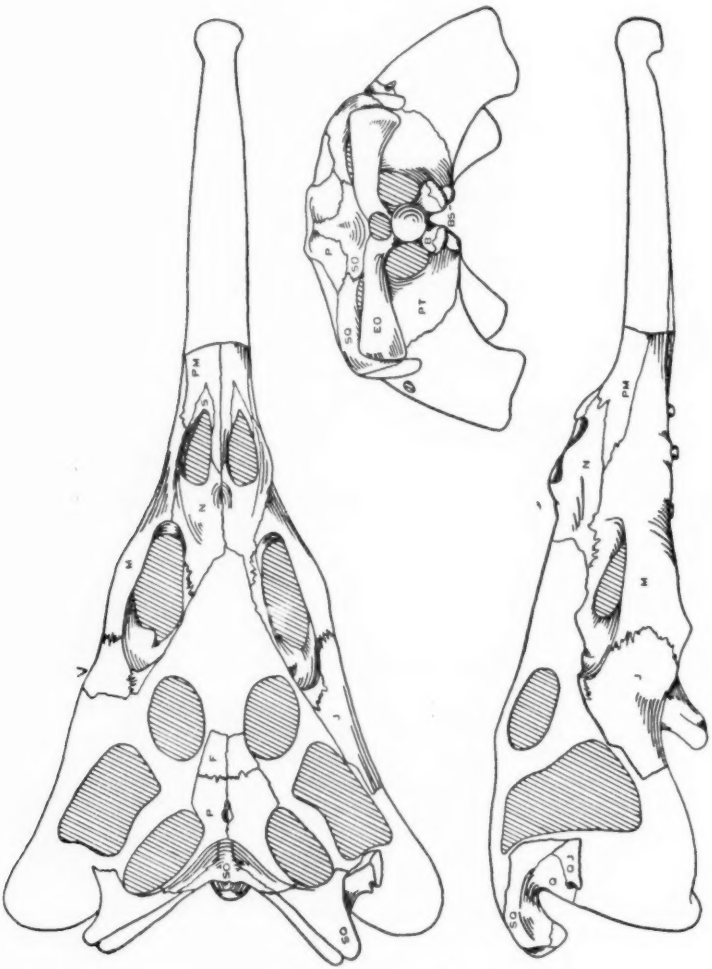

Fig. 1. *Paleorhinus scurriensis*, new species; W. T. M. Pal. Col., No. 539. Dorsal, lateral, and posterior aspects of skull. Approximately ¼ nat. size. Abbreviations: B, basioccipital; BS, basisphenoid; EC, ectopterygoid; EO, exoccipital; F, frontal; J, jugal; M, maxillary; N, nasal; P. parietal; PA palatine; PM, premaxillary; PT, pterygoid; Q, quadrate; QJ, quadratojugal; S, septomaxillary; SO, supraoccipital; SQ, squamosal. V indicates area through which section (Figure 3) was taken.

maxillary. Only one possible premaxillary alveolus is preserved in each bone. Posteriorly the premaxillary-maxillary sutures converge on the median line causing the premaxillaries to become narrow in this direction. They project into the choanae for a distance of 10 mm. at which point they have been destroyed by a transverse fracture through the skull. There is no contact with the palatines on the palatal surface.

As in *P. parvus* the relatively thick internarial septum rises somewhat above the level of the elevated narial rim. It is composed principally of the postero-mesial extensions of the premaxillaries which are overlapped laterally by the thin mesial wings of the septomaxillaries. The nasals project between the nares for a distance approximately one-fourth of the length of the septum.

In the majority of the phytosaurs this septum is formed by the septomaxillaries and the nasals. The premaxillaries are usually excluded from it by the juncture of the septomaxillaries in the median line. The preservation of the present specimen is such that when two adjacent bones have been damaged by weathering, a thin lamina of concretionary matrix remains standing to mark the position of the suture. These concretionary partitions are clearly seen in the region of the nares, and there can be little doubt that the condition exists as figured.

In his restoration of the skull, Lees (1907) indicates that the internarial septum in *P. bransoni* is composed altogether of the nasals which extend well forward anterior to the external nares and bound those openings completely. No septomaxillary elements are shown in the figures. Mehl (1928), however, has demonstrated the presence of these bones in the skull of *P. parvus* and their position in *P. scurriensis* cannot be questioned. Insofar as can be determined the relationship of the septomaxillaries to the premaxillaries and the nasals and the general construction of the internarial septum is similar if not identical in the two latter species, and there is, therefore, strong reason to expect similar conditions in *P. bransoni.*

Septomaxillaries: The septomaxillaries are relatively small V-shaped elements that form the anterior rims of the external nares. They project forward between the posterior wings of the premaxillaries for a distance of only 18 mm. The posteriorly directed mesial process of each bone extends well

into the naris where it laps against the septal portion of the premaxillary. Insofar as the writer is aware, a similar relationship is to be seen elsewhere only in *Paleorhinus parvus*. Mehl (1928), however, was unable to determine the posterior extent of the septomaxillaries in *P. parvus*, and therefore it is not known whether these elements joined each other in the median line in that form. In the present specimen, however, it is certain that they do not.

Maxillaries: The maxillaries are rather massive and elongate. Their maximum anterior extension on the lateral surfaces of the skull cannot be determined. In palatal aspect they form most of the anterior borders and part of the lateral margins of the choanae. They do not meet in the median line of the palate, being everywhere separated by the posterior continuation of the premaxillaries. Laterally the maxillaries occupy large areas on the sides of the skull and contribute greatly to the borders of the antorbital fenestrae. In fact, from the preservation of the specimen, it would appear that the maxillaries completely surround these openings. It seems probable, however, that at least a small part of the upper margins of the fenestrae would be contributed by the lacrimals. Beneath this opening the maxillaries are vertically thickened and become somewhat convex downward. The maxillaries contain 16-17 rounded alveoli of which the anterior five or six are decidedly the smallest. They are separated by transverse partitions and it appears that the teeth were not greatly crowded, a feature which has been interpreted as a youthful character in *Machaeroprosopus* (Colbert, 1947).

Jugals: The jugals are poorly preserved and can be only partially described. They articulate anteriorly with the maxillaries by means of angular interdigitating sutures. These sutures run upward and backward along the ridges created by the depression of the lateral skull surfaces just posterior to the antorbital fenestrae. In lateral aspect the ventral outline of the jugals is strongly arched permitting a wide view of the postero-ventral processes of the ectopterygoids. The relationships of the jugals to the orbits and lateral temporal openings cannot be accurately determined.

No recognizable portion of either lacrimal is preserved.

Nasals: The nasals are massive bones surrounding the external nares laterally and posteriorly. They are rugosely

sculptured dorsally, but are relatively smooth on the lateral surfaces. They project slightly between the narial openings, forming not more than one-fourth of the internal septum. Posterior to the nares the nasals are depressed and transversally constricted. Below the narial rim there is a moderate depression of the lateral skull surfaces which together with the constriction of the dorsal surface posterior to the nares lends a rather bulbous appearance to the nasal prominence. In lateral aspect the bones become wedge-shaped anteriorly where they separate the premaxillaries from the septomaxillaries for a short distance. They terminate laterally slightly in advance of the external nares. The nasals do not contribute to the borders of the antorbital fenestrae, but are separated from those openings by thin, backwardly directed processes of the maxillaries. Due to the loss of the dorsal region of the skull posterior to the nasal prominance the relationships of the nasals to the other bones of the skull cannot be determined.

Frontals: The frontals are poorly preserved and little can be said of them. The transverse diameter between the orbits appear to have been slightly less than in *P. bransoni*, and as a result the orbits probably looked more directly upward than in that form. The frontals meet the parietals along an almost straight transverse interdigitating suture.

Parietals: The parietals are proportionately of about the same size as in the type of *P. bransoni* although the maximum transverse diameter appears somewhat less than in that form. The sutural contacts are largely obscured in the present specimen, but the median and frontal sutures can be delimited to some extent. When seen from above the parietals appear as postero-median elements of roughly Y-shaped outline, the upper surfaces of which are rugosely sculptured. They are deeply excavated on either side by the superior temporal fenestrae. Posteriorly the parietals separate, each bone sending backward a wing-like process which lies above the supraoccipital and meets the antero-mesial branch of the squamosal. As a result of destruction of the upper surface of the posttemporal arcade on either side of the skull, the exact point at which this latter juncture occurs cannot be determined. It is the opinion of the writer that the suture must lie at about mid-length of the posttemporal bar. It is certain that it does not occur mesial to that point.

Some 12 mm. from the fronto-parietal suture an abnormally deep pit of roughly ovate outline excavates the parietals in the median line. It is certain that this pit, although much deeper than the adjacent sculpture, does not extend into the cranial cavity. Its relations to the internal structure

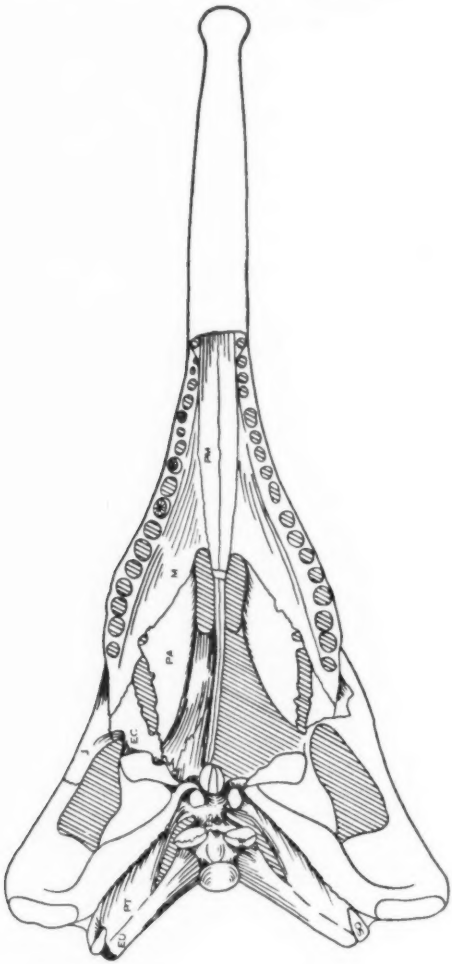

Fig. 2. *Paleorhinus scurriensis*, new species; W. T. M. Pal. Col., No. 539. Palatal aspect of skull. Approximately ¼ nat. size. For abbreviations see Figure 1.

of the cranium cannot be observed. The writer, therefore, cannot state definitely that this pit represents a pineal foramen, but its position is strongly suggestive. A pineal foramen is reported in *Mesorhinus* and Camp (1930) has demonstrated its presence in a juvenile specimen of *Machaeroprosopus lithodendrorum.* In view of this evidence and the fact that the epiphysis is strongly developed in adult individuals of *Machaeroprosopus* (Camp, 1930), vestiges of the pineal opening might be expected in immature members of the Phytosauria.

Squamosals: The squamosals are poorly preserved. It can be seen, however, that they are overlapped posteriorly by the paraoccipital processes of the exoccipitals. They articulate laterally in diagonal sutures with the quadrates. Apparently they form about one-third of the postero-mesial borders of the superior temporal fenestrae, but as pointed out above, the exact position of the parieto-squamosal sutures cannot be determined. The squamosals and quadrates are deeply excavated in the vicinity of the otic foramen. Lees (1907) described this area as containing an otic foramen in *P. bransoni.* In the present specimen, however, this area is well preserved and there is no indication of any structure that might have bounded the opening on the ventral side. It is, therefore, concluded that while the otic opening is deeply excavated in *P. scurriensis* it was present as a deep notch rather than as a completely bounded foramen, and the writer is inclined to agree with Mehl (1928) and others in questioning the accuracy of Lees' interpretation of this region in the genotype.

Quadrates and Quadratojugals: Only a small portion of the quadrate and quadratojugal from the right side of the skull is available for discussion. Strong indications of a quadrate foramen as shown by Lees in *P. bransoni* are to be seen on the postero-lateral surface of the quadrate. The opening is clearly visible in lateral aspect, but it is situated somewhat nearer the posterior edge of the quadrate than in that species.

Palatines and Pterygoids. The palatal vault with its extremely thin and delicate bones is by no means well preserved in the present specimen. In fact, it has been deemed inadvisable to attempt the removal of the matrix from this region on the left side of the skull. A longitudinal fracture has, however, caused the exposure of the sides and roof of the palatal vault

on the right side and, although badly broken, the palatine and pterygoid can thus be delimited with some degree of certainty. The posterior limits of the choanae cannot be determined in the specimen.

The palatines and pterygoids form the greater portion of the high steeply vaulted palate posterior to the choanae. The former elements are of the characteristic phytosaurian construction with the usual horizontal and vertical plates set off from each other at angles approaching 90 degrees. Laterally and anteriorly the palatines are in sutural contact with the maxillaries; postero-superiorly they are overlapped by the pterygoids, whereas postero-laterally they meet the ectopterygoids. When seen from below, the hoizontal plate of each pterygoid is broadly triangular in outline. The base of this triangle is somewhat rounded and thickened whereas the posterior leg forms the internal boundary of the pataline foramen, which in *P. scurriensis* is slightly less than one-half (60 mm.) of the total length of the palatine. Anteriorly the mesial border of the horizontal plate forms the postero-lateral rim of the choana, but other relationships of the vertical plate in this region cannot be determined. Each palatine terminates anteriorly, on the lingual surface, in a sharp pointed process which wedges out in the maxillary at a point just behind the anterior borders of the choanae.

The badly broken right pterygoid only is preserved in the palatal region. It forms part of the vertical sides of the palate and enters into the palatal roof to an undetermined extent. Along the median line of the palate there is a rather sharp, ventrally directed carina which is formed, at least in part, by the joining of the downward turned mesial edges of the pterygoids. This carina continues forward into the choanae and there probably meets the septal portion of the premaxillaries although the imperfection of the specimen in this region makes it impossible to state the exact position of the juncture. When seen from behind both pterygoids appear as broad-wing-like plates of bone. There is no indication of the presence of the quadrate suture on the preserved surfaces of either bone. Below, downwardly and anteriorly directed flange-like processes fold around the anterior and lateral surfaces of the basipterygoid processes.

There is no evidence of vomerine sutures and the writer is

inclined to believe that these elements did not appear in the palatal aspect in *P. scurriensis*.

Ectopterygoids: The right ectopterygoid is partially preserved. The antero-lateral process articulates with the maxillary and jugal and surrounds the postero-lateral half of the palatine vacuity. In lateral aspect the bone projects

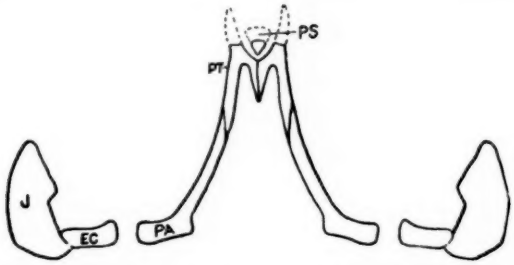

Fig. 3. *Paleorhinus scurriensis*, new species; W. T. M. Pal. Col., No. 539. Transverse section through skull (V, Figure 1), somewhat diagrammatic.. PS, parasphenoid process. ½ nat. size.

downward well below the lower border of the upwardly arched jugal. It underlies the outer process of the pterygoid.

Supraoccipital: The supraoccipital is a relatively large triangular element situated in the postero-mesial notch of the skull. From above it is more completely visible than in *Paleorhinus bransoni*, approaching in this respect, the condition found in *Promystriosuchus ehlersi*. It forms only a small part of the upper boundary of the foramen magnum and extends upward terminating against the posterior eave-like extension of the parietals just below the level of the skull roof. Laterally the bone extends outward on either side in narrowing wing-like processes to articulate with the squamosals on the posterior face of the skull about mid-length of the post-temporal arcade. Supero-laterally it is bounded by the parietals whereas ventrally it unites with the exoccipitals along horizontal sutures.

Exoccipitals: The exoccipitals are of the characteristic phytosaurian form although the paroccipital processes appear to be somewhat more elongate than in the majority of the genera. Except for the small mesial portion, contributed by the supraoccipital, they bound the foramen magnum completely and extend downward onto the occipital condyle form-

ing a major part of the neural surface of that process. The paroccipital processes are relatively straight, extending strongly backward and outward to terminate in rather broadly expanded buttresses against the squamosals. The elongate but vertically narrow posttemporal fenestrae are situated at about mid-length of this process.

Basioccipital: The basioccipital comprises the greater part of the rounded knob-like occipital condyle which is set off from the remainder of the bone by a strong but relatively short neck. It is excluded from the floor of the foramen magnum by the junction of the exoccipitals in the median line. Ventrally the basioccipital is divided along the median line by a deep groove thereby forming the posterior halves of the strongly developed roughened tubera. Supero-laterally it is in contact with the exoccipitals whereas antero-ventrally it joins the basisphenoid.

Basisphenoid: The basisphenoid is a large, irregular median element situated just anterior to the basioccipital with which it is cojoined along a very tenuous suture. The connection between the two bones is much less stout than in the larger phytosaurs. Postero-ventrally this suture runs transversely across the large downwardly and anteriorly projecting tubera of which the basisphenoid forms the anterior one-half. Antero-ventrally the bone is again expanded on either side of a deep median pit into two strong, downwardly and laterally projecting basisphenoid processes which are enclosed anteriorly by the median, recurved flanges of the pterygoids. Much of the matrix still remains in this region of the skull and other features of the basisphenoid and adjacent elements are therefore obscured from view.

Laterosphenoids: Insofar as they can be seen the laterosphenoids underlie the frontals and parietals medially. They are broken on either side of the skull, but it is apparent that they also underlie the postfrontals to some extent. Posteriorly they meet the proötics, but are excluded from contact with the supraoccipital by the junction of proötics and the parietals in front of those bones. The bones are rather bulbous in appearance beneath the parietals, but taper gently inward anteriorly beneath the frontals.

Proötics: The proötics are inadequately exposed, but it can be seen that they are relatively large. They are bounded

above by the supraoccipital and antero-posteriorly by the parietals.

GROWTH FACTORS IN THE GENUS *Paleorhinus*

The size and robustness of the type skull of *Paleorhinus bransoni* indicate that the individual was adult or nearly so whereas there can be little doubt as to the immaturity of the present specimen. The question of growth factors in the genus *Paleorhinus* may therefore be examined.

Colbert (1947) has attributed certain variable characters in *Machaeroprosopus* to factors of growth. The extent to which these criteria (robustness, prenarial crest, posterior expansion of premaxillaries, spacing of teeth, and proportion of prenarial length to skull length) can be applied to the genus *Paleorhinus* is not completely clear, but most of them appear to be of at least minor importance.

Differences in robustness are clearly evident in skulls of *P. bransoni* and *P. scurriensis*; the latter is more lightly constructed in every detail. The presence of prenarial crests within the Phytosaurininae appears to be peculiar to *Machaeroprosopus*, *Phytosaurus*, and in somewhat less degree to *Leptosuchus*. The rostrum in *Paleorhinus* apparently underwent some increase in overall massiveness during growth, but nothing resembling the crests of the above named genera is evident. A posterior expansion of the premaxillaries is present in *P. bransoni*, but is of less magnitude than in *Machaeroprosopus*. This region is missing in the present specimen. The teeth in *P. bransoni*, while not approaching the crowded condition found in the adult *Machaeroprosopus* skull are, nevertheless, more closely spaced in the Texas specimen. The changes in proportion of the prenarial length to skull length cannot be established on the basis of available material. The presence of a parietal foramen has been discussed above.

Two features observed in the study of the skull of *P. scurriensis* are perhaps significant although their variability is perhaps most important from the phylogenetic standpoint. The condition of the septomaxillary as described in the foregoing discussion is not seen in the more advanced forms. Two small bones in the same relative positions as in *P. scurriensis* are figured in *Mesorhinus* (Jaekel, 1910) and there is reason to believe that these elements represent the septo-

maxillaries in a much reduced and primitive condition. If *Mesorhinus* is accepted as a primitive structural type, and *Paleorhinus* is considered as an intermediate stage, the proportional changes occurring in the phytosaur skull during the Triassic will clearly demonstrate the development of the remarkably large median septal elements of such advanced American forms as *Machaeroprosopus*.

The second feature, the large size of the palatine foramen, is a feature which appears to be peculiar to the more primitive Phytosauria (with the possible exception of *Promystriosuchus*). It is therefore assumed that immature skulls in which a parietal foramen still persists might still reflect this primitive condition of the palatine foramen. It is certain that the openings are larger in *P. scurriensis* than in *P. bransoni*.

The effect of sexual dimorphism upon the variability of these characters is at present unknown. They may be summarized as follows:

CHARACTER	YOUTHFUL CONDITION	ADULT CONDITION
Robustness	general trend toward	increase in massiveness
Prenarial crest	absent	absent
Posterior expansion of Pmx	not observed	present, but of small magnitude
Spacing of teeth	wide	narrow
Prenarial length/skull length	undetermined	
Size of septomaxillaries	small	larger?
Palatine foramen	large	smaller
Pineal foramen	persistent	obliterated

COMPARISONS WITH OTHER FORMS

A comparison of the skull of *Paleorhinus scurriensis* with the two previously described *Paleorhinus* species is tabulated below:

CHARACTER[3]	*P. bransoni*	*P. parvus*	*P. scurriensis*
Nares anterior	3	2	1
Squamosal short, heavy	1	—	2
Quadrate foramen visible in lateral view	1	—	2
Otic opening a notch	1	—	2
Skull flattened dorso-ventrally	2	—	1
Internarial septum composed of Pmx. and Na.	—	0	1
Septomaxillaries not meeting in median line	—	0	1
Palatine foramina large	2	—	1
Posttemporal fenestra elongate	2	—	1
Number of maxillary teeth	16	17	16–17

[3] 1-3 indicates degree of development; No. 1 indicates maximum development. 0 indicates a probable difference, but degree not completely observed.

Differences between the present specimen and skulls of *Leptosuchus*, *Brachysuchus*, and *Machaeroprosopus* are to be found most abundantly in the above table. In fact, no points of complete agreement with the listed characters are to be found except in the open otic notch. *Mystriosuchus* and *Rutiodon* are completely different in appearance and general proportions. *Angistorhinus* is a relatively primitive genus that exhibits many similarities to the present skull. Most of these may be considered as of only superficial importance and the characters of the subfamilies are adequate for definitive purposes.

There is much similarity between the skull of *Paleorhinus scurriensis* and that of the nearly contemporaneous Texas form *Promystriosuchus chlersi* Case. Both are of relatively small size with slender rostrae. The nares are anterior in each, but they are somewhat more elevated in the latter. The depression of the facial and posterior cranial portions is more pronounced in *Promystriosuchus*. The posttemporal arcade is apparently in about the same stage of development in both skulls although the squamosals are more strongly developed posteriorly in *Paleorhinus scurriensis*. The number of teeth is approximately the same. The elongate and broadly exposed parasphenoid process of *Promystriosuchus chlersi* is remarkably different from that in all other phytosaurs, including *Paleorhinus*. The palate is more steeply vaulted and the palatine foramina are much larger in *Paleorhinus scurriensis*.

SYSTEMATIC POSITION

The present specimen is in complete agreement with the characters listed by Camp (1930) as typical of the subfamily Phytosaurininae and is obviously primitive within that group. Its similarity to the paleorhinid skull as exemplified in *P. bransoni* is obvious, but its position within the genus is obscured by the fact that it pertains to an immature individual in which important comparative features are not fully developed. For this reason it seems advisable to defer further decisions on the systematic position of *P. scurriensis* in the hope that future discoveries in the Dockum group may provide an adult individual.

GEOLOGICAL IMPORTANCE

Recognition of the genus *Paleorhinus* in Texas again raises

the question of terrestrial Triassic correlation in western North America. Detailed correlation, however, is hazardous even within the relatively small areas of continuous Dockum exposures. In many instances it is impossible to prove the age equivalence of exposures that are separated by only short distances. It is not surprising, therefore, that attempts to integrate the present stratigraphic information concerning the Dockum and other Triassic deposits have met with little success.

In view of the paucity of identifiable invertebrate fossils in the continental Triassic redbeds and the extreme degree of lithologic facies variation within the sediments, the evidence afforded by vertebrate remains becomes of great stratigraphic importance. Numerous discoveries of these remains have provided surprisingly few instances of genera common to two or more areas. Several supposed occurrences of faunal duplication have been reported, but in most cases the identifications have been based upon inadequate material. The validity of such occurrences must, therefore, be accepted with scepticism.

Two phytosaur genera, *Angistorhinus* and *Paleorhinus*, originally described from the Popo Agie[4] of Wyoming, are known to be present in the Dockum of Texas; the former through at least two occurrences in the Big Spring area (Stovall and Whorton, 1936; Gregory, 1944) and the latter through the present specimen. Neither of these forms has yet been reported from Dockum deposits farther to the north which are presumably somewhat higher stratigraphically than the exposures in Scurry and Howard counties. In fact, the skull of *Paleorhinus scurriensis*, coming from a level just above what is considered as the Permian-Triassic boundary in Scurry County, may represent the oldest phytosaur yet reported from the Dockum. Exact information regarding the stratigraphic position of the Texas *Angistorhinus* specimens

[4] Reeside (1929) proposed that the name Jelm formation be substituted for the Popo Agie formation, basing his argument upon structural, stratigraphic, and lithologic considerations. Others later concurred in this opinion. Without regard to the apparent desirability of such a substitution, however, it must be stated that the term Popo Agie formation has found wide usage as a vertebrate horizon within a section of beds relatively barren of identifiable vertebrate remains and as such still possesses considerable value for purposes of vertebrate paleontologic correlation. The term as here employed refers only to that portion of the Jelm formation from which diagnostic vertebrate remains have been described.

is not available, but they must have come from a level somewhat higher than that which yielded the present specimen. Information concerning the relative positions of the two genera in the Popo Agie is likewise lacking, but insofar as the writer can determine, the two forms were never found in association.

In general, proposed correlations betwen the Dockum and Popo Agie have been couched in rather general terms, but the trend has been to indicate an *in toto* age equivalence for the two. The writer is of the opinion that the equivalence of the Popo Agie and the lower part of the Dockum group can now be demonstrated within acceptable limits of error. However, this equivalence which is most accurate in the Howard and Scurry County area must become less distinct laterally. The vertical limits of equivalence cannot be accurately determined, although it is apparent that the Popo Agie sediments represent a much shorter period of deposition than do those of the Dockum group.

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Department of Geology
Texas Technological College
Lubbock, Texas

REVIEWS

Cybernetics; by NORBERT WIENER. Pp. 194. New York, 1948. (John Wiley & Sons, $3.00).—The title of the book, we are told by its author, means "control and communication in the animal and the machine"; this happy coinage of a new word for a new subject should be applauded by less literate scientists as scoring against those who have scornfully concluded that scientists need lessons in linguistics.

Wiener's book makes significant contributions to several fields. In physics it calls attention to a change in the concept of time which attended the passage from Newtonian to statistical mechanics. The author holds that Newtonian time is reversible, a kind of time in which nothing new can ever happen. Statistical mechanics, particularly in the form of quantum theory, has significance only for an irreversible time ("Gibbsian time" according to Wiener—a rather strange baptism), a time "in which there is always something new." This irreversible time is essentially the one advocated by Bergson as characteristic of biological phenomena, and the point is made that physics, having achieved a stage in which it can build automata that resemble organisms, must take seriously the irreversible time of Bergson.

Nowhere is the interesting connection between Gibbsian physics and Lebesguian mathematics so clearly outlined as in the present book. And the statement bristles with challenges unpleasing to the devotee of Gibbs. Thus, we find an appreciative acknowledgement of Gibbs' discovery of a relation between time averages and space averages, followed by a reminder that "in the method by which he tried to show this relation he was utterly and hopelessly wrong." It was a surprise to the reviewer that Gibbs ever tried to establish such a relation; for it appears from his writings that he contented himself with the brilliant postulation of what he called the canonical ensemble, and that he did not worry about ergodic problems. At any rate, Wiener's second chapter brings the logical and mathematical situation surrounding the ergodic hypothesis soundly up to date.

A review of the author's important theories of statistical prediction and of filters is included in the book. This will be of some interest to mathematicians and theoretical physicists, and will have but little appeal to most readers. The value, even to the specialist, of the mathematical portions is reduced by many unfortunate typographical errors which make the detailed examination of analytical steps rather exasperating in several important sections of the book.

The engineer will gain a deepened insight into the workings of

feedback mechanisms. There is in chapter 4 a beautiful discussion and a simple classification of the various types of feedback systems from a general and formal point of view. A great deal of information about the action and construction of calculating machines is offered, and interesting comments on numerous problems of communication engineering are found throughout.

The book attempts to appraise neuro-physiology in a new way. Adopting a forthright behavioristic attitude, Wiener "explains" the workings of the brain in terms appropriate to the action of modern calculating machines. There is apparently an extensive parallelism between neural anomalies, or even psychopathic conditions, and the malfunctioning of electric calculators; this parallelism is skillfully exploited and made highly informative and suggestive.

Considerable space is given to the social consequences of our ability to construct automata. Enormous popular interest has seized and will continue to seize upon this lurid aspect of cybernetics, but there is no need to dwell upon it in a brief review.

As to the bearing of his researches upon philosophy, the author makes two basic claims. The first is in his thesis that all regularities in nature, all laws, are essentially of a statistical sort. Exact laws, like that of gravitation, are limiting cases, are in fact not exact in detail, and represent matters of little contemporary interest, to judge from the tenor of Wiener's argument. Confirmation for this thesis is seen in the quantum theory of the atom. In my opinion such argumentation is rather artificial, suggesting an extreme and self-defeating form of empiricism. For while it is true that the interpretation of quantum laws is a statistical one, the laws themselves, like Schrödinger's equation, are still exact. Even if one admits, as one must, that detailed observations scatter within a certain range and are in accord with the laws of chance, important parts of our experience nevertheless remain mysteries. For there are still laws of nature, and presumably exact laws, which regulate phenomena "in the mean." Thus the attitude of *nil mirari*, displayed throughout the book with respect to matters of traditional philosophy, comes to grief at this point; for it is just as hard to account for the statistical laws of quantum physics as it is to account for the laws of classical physics. The shift of emphasis effected by Wiener's thesis, while timely and useful, seems to solve no philosophical problem.

The second point of importance is Wiener's insistence that a proper understanding of the meaning of information, defined as negative entropy, provides a uniform basis for thermodynamics, communication engineering, and psychology. Here again it is typical that no place is given to consciousness, which the author

regards as superfluous. In this, many scientists will follow him. But there seems to be a strange defect in the whole philosophy of cybernetics which arises from its concern over behavior in a very narrow sense. Suppose we admit that information can be formally defined in terms of the varying amplitude of some carrier. Does it not matter greatly what this carrier is? Every science is intensely interested in the substratum which communicates its signals; it is important indeed whether they are acoustic, seismic, electromagnetic, or perchance gravitational. The philosopher will want to ask Dr. Wiener to commit himself more clearly than he does in this book on the *nature* of the information, which he formally defines, that roams around in what is called the human mind. Until he does he teaches an interesting analogism quite similar to one well-known in physics which embraces mechanical, acoustic and electrical vibrations.

Perhaps this is all he intends, and it would be a noteworthy scientific achievement, amounting in the end to something like the following. We now have a set of mechanical, acoustic and electrical analogies (mass, stiffness of a spring, force, etc.). By means of them, the solution of a problem in mechanical vibrations becomes at once a solution of a problem in acoustics and a solution of another problem in alternating current networks. This circumstance is most fortunate and scientifically useful. But it does not allow us to say that mechanics, acoustics and electricity are basically the same thing. Wiener's contribution is, it seems, in the suggestion that the known analogies can possibly be extended to certain phenomena in the animate world. To drive the philosophical implications of cybernetics beyond that point is at present unwarranted.

HENRY MARGENAU.

Practical Spectroscopy; by GEORGE R. HARRISON, RICHARD C. LORD and JOHN R. LOOFBOUROW. Pp. xiv, 605. New York, 1948 (Prentice-Hall, $6.65).—The first practical spectroscope was developed by G. R. Kirchhoff and R. Bunsen in 1859. They showed that the spectroscope could be used for chemical analysis, and with their instrument they discovered several new elements and demonstrated the existence of many of the then known elements in the sun. From this beginning spectroscopy has had a tremendous growth, especially in the last thirty years during which guiding quantum theories have been available. Today the spectrograph serves as a powerful research tool in all branches of science.

At the Massachusetts Institute of Technology the authors, who are a physicist, a chemist, and a biophysicist respectively, have been operating what is probably the largest and best equipped spectroscopic laboratory in this country. In this book they synthe-

size their viewpoints so well that all who use spectroscopic techniques, no matter what their main scientific interest, will find in it much of value. No topics are treated in an advanced way, but references are always given so that the reader may without delay delve further into the literature of any subject. The authors avoid the historical approach. They give a comprehensive view of the present status of all the instruments and techniques of ordinary spectroscopy, together with the main results of the supporting theory in every case. They do not discuss the recently very active field of microwave spectroscopy.

After a first chapter which gives a birds'-eye view of spectroscopy as a scientific tool, there follow chapters on the various types of spectrographs and their adjustment, care, and illumination, photography of the spectrum, light sources of all kinds, and the identification of spectrum lines. The next two chapters summarizing the quantum mechanical interpretation of atomic and molecular spectra and the correlation with atomic and molecular structure form a clearly written introduction to these modern revolutionary developments. Further chapters on the measurement of spectral intensities, photographic photometry, absorption spectrophotometry, both qualitative and quantitative spectrochemical analysis, spectroscopy of the infrared and ultraviolet, Raman spectroscopy, and the use of the various types of interferometers are packed full of useful information.

Appendices giving the sensitive lines of each of the elements arranged both according to elements and to wave-lengths should prove of considerable value because of the compact arrangement and the inclusion of recent measurements. Numerous photographs and line drawings form an attractive feature of the book. The style is direct, forceful and economical.

The authors of *Practical Spectroscopy* are to be congratulated for their production of such a complete, well-written account of modern experimental spectroscopy. Everyone concerned with any aspect of the subject will find this book indispensable.

W. W. WATSON

The Interpretation of Spectra; by Wm. M. Venable. Pp. 208; 12 figs., 73 tables. New York, 1948 (Reinhold Publishing Corp., $6.00).—This small book will delight the iconoclast. It is an assiduous attempt to account for *all* optical and x-ray spectra on classical electromagnetic theory. Quantum theory and quantum electrodynamics are dismissed as being hypotheses having little relation to observed data. The problem which first precipitates this drastic philosophy is the correlations between the principal spectrum of hydrogen and its many-line spectrum. By treating

the hydrogen atom as a combination of three "sub-atoms" the author claims to have accounted completely for the lines in the hydrogen spectrum; the "energy levels" (a term always to be employed in quotation marks) that result from this model are relatively few in number but can intercombine in rather arbitrary ways to account for the spectral lines. This theory is then extended to helium and the more complex atoms, all of whose nuclei are made up of various combinations of "sub-atoms" in a way that is amazing, to put it mildly. (Incidentally, it is the contention of the author that the alpha particle is *not* a helium nucleus, Rutherford's work notwithstanding.) Inevitably, the proposed model of the atom must meet up with the vast mass of data derived from nuclear reactions, but it appears sufficiently flexible to hurdle that barrier, even if somewhat arbitrarily.

It should be noted that the author is by no means unaware of contemporary theory and experiment; he simply does not subscribe to such work. He derives his philosophy from a remark which he ascribes to Max Planck:

> "Since nothing probably is a greater drawback to the successful development of a new hypothesis than overstepping its boundaries, I have always stood for making as close connection between the hypothesis of quanta and classified dynamics as possible, and for not stepping outside of the boundaries of the latter until the experimental facts leave no other course open."

Admittedly, the gymnastics required to remain with the confines of classical theory are strenuous (the book contains sixty pages of tables), but the author has mastered them to his own satisfaction, if not to this reader's. RICHARD F. HUMPHREYS

Organic Reactions. Volume IV. Edited by ROGER ADAMS, Editor in Chief, WERNER E. BACHMAN, A. H. BLATT; LOUIS F. FIESER, and JOHN R. JOHNSON. Pp. viii, 428. New York, 1948 (John Wiley and Sons, $6.00).—This volume, the fourth to appear in a series devoted to the application of specific organic reactions, is entirely worthy of its precursors. Since the appearance of the first volume in 1942, *Organic Reactions* has come to be regarded as indispensable to the organic chemist and each new volume is eagerly anticipated. The present volume consists of eight chapters, the first two of which are devoted to the Diels-Alder reaction and are written by Milton C. Kloetzel and H. L. Holmes respectively. Other chapters are: The Preparation of Amines by Reductive Alkylation, William S. Emerson; The Acyloins, S. M. McElwain; The Synthesis of Benzoins, Walter S. Ide and Johannes S. Buck; Synthesis of Benzoquinones, by Oxidation, James Cason; The Rosenmund

Reduction, Erich Mossettig and Ralph Mozingo; and the Wolff-Kishner Reduction. Following the usual form established in the first volume, each chapter considers the mechanism, the scope, and the experimental details of the reaction. Several illustrative preparations are given in detail and a complete tabular survey of the applications of the reaction reported in the literature supplements each chapter. The critical evaluations of the reaction details by the authors are particularly valuable, coming as they do from wide first hand experience.

Perhaps the only criticism which this reviewer is inclined to make of this highly commendable series, is that certain of the chapters to appear are of less general significance than could be desired; moreover, in the case of several chapters, e.g., the Diels-Alder reaction, comprehensive treatments of the topics have appeared elsewhere. The reviewer feels that ideas for future chapter topics might be welcomed by the editors and suggests the Hoesch and Gatterman syntheses of aromatic ketones and aldehydes, or perhaps the degradation of amines by the methods of Hofmann, von Braun and Emde.

ALFRED H. FRYE

The Chemical Constitution of Natural Fats; by T. P. Hilditch. Pp. 554. New York, 1947, John Wiley and Sons, Inc. ($9.00)

The author has classified the natural fats on the basis of their sources, and has emphasized the close relation between component acids in fats and their origins. Readers can thus get many new hints towards deciding the direction of their later work in this field. In this second edition, this principle of classification is also adopted and further developed.

The natural fats are dealt with separately in three groups: those of aquatic flora and fauna, land animals, and vegetables. These are further classified under species and family, as well as under different parts of the body in some instances. On the other hand, about one hundred important individual fatty acids are discussed in another chapter, thus giving a clearer understanding of the "building-stones" of fats. The natural forms of glycerides in vegetable and animal fats are discussed in three chapters, including the crystallization method for their separation, although at present complete isolation is still not successful. Recent data of synthetic glycerides are also introduced for convenience of comparison with the natural ones. Many experimental techniques, data and apparatus, such as fractional distillation in vacuo, separation of acids by the lead salt, as well as by the newly developed lithium salt method, and low temperature crystallization, are described in detail. Moreover, recent important literature published after 1940 are collected up to 1945 (although some data published in the Orient were not

available at that time), thus giving fresh information to researchers in this field. Because of the form of this book, somewhat complicated indexes are needed, so that in this edition an index of plant families was added. The old indexes, such as the index of fats and waxes of different origins, index of individual fatty acids, index of individual glycerides have been retained.

The richness of information and accurate data of this book will make it easier for readers to do better future work. This is a good reference for the oil and fat chemists as well as botanists, zoologists and bacteriologists. However, in my opinion, it is desirable and might be more stimulating if there were present a chapter dealing with those sterols obtained from natural fats, although they are not, as the author pointed out already, a component of the fat — the glycerides of fatty acids. The interest which the earth's scientists are beginning to take in the organic components of muds and sediments may recommend this reference book to their attention.

S. L. LIU

When the Earth Quakes; by JAMES B. MACELWANE; S.J. Pp. xi, 228; 252 figs. Milwaukee, 1947 (The Bruce Publishing Co. $5.00).—In this book one of the foremost seismologists attempts to explain his science to educated laymen. The general plan of the treatment resembles that followed by several other books in the same field. Starting with a discussion of earthquake behavior, documented by the recorded effects of 18 major shocks in modern times, the author proceeds to an explanation of causes; of methods and techniques used in the scientific study; of the earth's internal structure as deduced from earthquake records; and of practical applications of seismic principles in the search for mineral deposits. Considerable attention is given to the engineer's interest in seismology, in connection with problems of earthquake-resistant construction. A chapter is devoted to rock bursts in underground workings, and another to microseisms caused by storms at sea. An appendix of 20 pages outlines some of the principles of physical geology.

Without question any intelligent reader can get from the book much interesting and accurate information. The style is clear, essentials of the subject are well covered, and the language is reasonably non-technical. An extensive glossary defines terms with which most lay headers are not familiar. Numerous good illustrations supplement the text, but some of the figures are open to criticism. Of more than 40 maps, only two are equipped with graphic scale, and six others have geographic coordinates; thus most of the maps lose much of their value to readers. Many halftones showing seismographs and other technical instruments are of dubious value,

since in general these pictures give no hint of principles on which operation of the instruments depends. A few well constructed diagrams would be far more serviceable.

Scientists other than those well versed in seismology will find that the book has much instructive reading, and that it will give service as a reference work for some subject matter. One of the appendices gives a long list of publications dealing with earthquakes and seismic studies. Unfortunately these are not arranged in alphabetical order of authors. CHESTER R. LONGWELL

Fundamentals of Physical Science; by KONRAD B. KRAUSKOPF. Pp. xii, 676; 330 figs. Second edition, New York, 1948 (McGraw-Hill Book Co., $4.50).—Krauskopf's textbook attempts two things: first to survey all the physical sciences—astronomy, physics, chemistry, geology—presenting in brief form the principal conclusions of each that the intelligent layman would profit from knowing, and second to demonstrate to the same layman how the scientific method has reached those conclusions. Such aims would seem to be mutually incompatible. Elementary courses even in a single science are expected to convey so much information and so much basic doctrine that almost without exception they are authoritarian in presentation, and the student who continues in science learns that science is principally inquiry and doubt only at a later stage, commonly in graduate school if at all. On the other hand, courses of the "cultural" type, intended to introduce the layman to the scientific method, ordinarily select small segments of science which are used to exemplify the method, and no attempt is made to present the full sweep of scientific discovery even for one major field. But Krauskopf has not been content to discuss only simple and limited portions of the physical sciences, but has tried to cover all their major aspects, including such diverse topics as colloid chemistry, air-mass analysis, and the general theory of relativity, manifestly expecting the student to understand each of them, and he has at the same time restricted himself in mathematics to the simplest arithmetic and algebra and an occasional graph. How then can he hope to give the student even an inkling of the real meaning of the scientific method?

The extraordinary thing is that he has succeeded. There is hardly a major conclusion of physical science today that is not at least touched on in this book, yet the student is made constantly aware of the tentative groping process that led to those conclusions; he is introduced not only to the fields where the scientific method has made its great successes but also to those where it is still cautiously feeling its way. In the reviewer's opinion, two characteristics of the book have made this possible. The first is the historical approach, which is used in subject after subject; in-

stead of first presenting the magnificent simplicity of the generalizations and then showing how well they explain the facts, Krauskopf has tried first to present the bewildering complexity of the facts and then to show how certain gifted individuals, many of them mentioned by name, piled inference upon inference until they arrived at general "law." In so doing he has cut across the conventional divisions between the sciences whenever the argument required, and has grouped the subjects treated into six sections, centering around the concepts of gravitation, the atom, the electron and the nucleus, chemical reaction, earth history, and the universe beyond the earth.

The second characteristic of the book is scientific humility, the constant admission that science and its method are not all powerful but proceed by trial and error, succeeding in one field but failing to advance in another, and the constant emphasis on the concept that even science's most cherished doctrines are either postulates or inferences which may require modification in the future as such postulates as "no action at a distance" and such inferences as the law of the conservation of matter have required modification in the past. As a result, the serious reader sees rising before him the whole structure of scientific hypothesis, not springing full-grown like the goddess Athena, but being put together piece by piece through the patient efforts of many men.

If the reviewer has any qualms about the book, it is precisely because of certain deviations from the two characteristics mentioned. Thus the historical approach is so successfully used for the theory of gravitation that one wonders why the electron theory of electricity was introduced ahead of the discussion of electric currents. Again, the inductive approach is occasionally abandoned for the authoritarian, and oversimplifications such as the neat separation of the geologic eras by catastrophic revolutions creep in. Probably however such deviations were enforced by the necessity of crowding the immense variety of information treated into a book of reasonable size and cost. One is tempted also to suggest alternative arrangements of the subject matter, but as the present arrangement was worked out on the basis of practical teaching experience, it is not to be tampered with lightly. As it stands, the book is an extraordinarily comprehensive review of physical science from which, however breathless he may become as he jumps from subject to subject, the student of reasonable intellect and interest cannot fail to attain an appreciation of both the results of science and its method. JOHN RODGERS

Crystal Structures; by RALPH W. G. WYCKOFF. Pp. 491. New York and London, 1948. (Interscience Publishers, Inc., $8.00; looseleaf binding, 8.5 x 10.3 inches.) There can be no question of

the need for, or value and usefulness of, a new edition of Dr. Wyckoff's well-known compilation of the structures of crystals. The pagination in no less than twenty-seven groups will at first seem a considerable objection to the new edition, but this feature is a small price indeed to pay for the page replacements containing additions or corrections, promised in the Publisher's Note at the beginning of the book. By placing the chapter number and title at the top of every page and providing an extensive table of contents, adequate means is provided for finding the descriptions of crystal structures.

The plan of the book is similar to that of the previous editions: Chapter I, Preface and introduction; Chapter II, Structures of the elements; Chapter III, Structures of the compounds RX; IV, RX_2; V, R_mX_n; VI, $R(MX_2)_n$; VII, $R_n(MX_3)_p$, constitute the present section I of the book. Section II, Chapters VIII through XII, will cover the remaining inorganic crystal structures including silicates; and organic structures will be described in Section III.

Sections II and III together will have to be somewhat smaller than Section I, to be accommodated within the looseleaf binder furnished with Section I. Dr. Wyckoff may find it hard to confine his expanding book to that space, but few will object to an additional looseleaf binder if and when it becomes necessary.

This monumental work is a necessary reference for all crystallographic workers. Crystallographers owe a great debt of gratitude for Dr. Wyckoff's efforts in assembling it.

HORACE WINCHELL

A Source Book in Greek Science; by MORRIS R. COHEN and I. E. DRABKIN. New York, 1948. Pp. xxi, 579 (McGraw-Hill Co., $9.00). The need for our enlivening the traditional teaching of science courses by historical perspective has often been emphasized. Unfortunately, the task of organizing the material required for that task had proved too large and time-consuming for working scientists. The publication of "A Source Book in Greek Science" has eliminated this obstacle.

For it presents between the covers of a single volume most of what is likely to be regarded as interesting and useful in Greek literature by the student of the natural sciences. The selections are well made. Some of the passages appear in English translation for the first time. The book is not a collection of fragments; it presents the story of each science in fairly coherent form, the connecting material being skillfully provided by the authors wherever the original requires an introduction or an explanation to fill a gap. Particularly noteworthy is the modern outlook which asserts itself not only in the arrangement of the historical material but in

the footnotes and in the connecting passages as well.

Physics gets the lion's share of attention, and it needs it perhaps more than the other sciences because of the indifference and, to a large extent, misrepresentation which Greek physics has suffered in its treatment by physics teachers. A good deal of Aristotle is included, and it is no longer defensible in view of the publication of this volume to reiterate the textbook judgment which condemns Aristotle as having a non-scientific approach. Next in extent of treatment are medicine and biology; mathematics, astronomy and chemistry fill the remainder.

This book will find its way into all scientific libraries and, we hope, into the libraries of many science teachers.

HENRY MARGENAU

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